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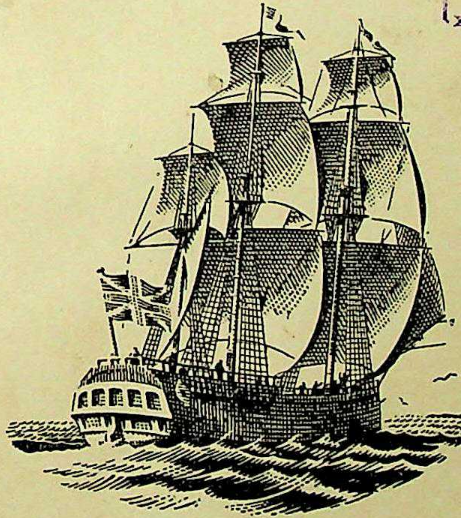

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Editor: TREVOR I. WILLIAMS, M.A., B.Sc., D.Phil., F.R.I.C.
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पुस्तकालय
गुरुकुल कांगड़ी विश्वविद्यालय
हरिद्वार

Benjamin Franklin

Benjamin Franklin, the two hundred and fiftieth anniversary of whose birth falls in January 1956, was a man equally effective and at ease when investigating the behaviour of concordant inanimate nature and when concerned with the conduct of discordant humanity. In all his undertakings he showed a supreme ability to distinguish the essential from the inessential, the significant from the obvious but trivial. With this quality went his clear-headed power of first determining what ought to be done and then of finding the appropriate means for doing it. A general perspicacity and shrewdness characterized his conduct as a business man and played some part in his excellence as a writer. These powers were, of course, supplemented by many other virtues and by certain other human characteristics.

Franklin is most widely known as the man who established the electrical nature of lightning and designed the first effective lightning conductor, and this is certainly one, but by no means the only one, of his great services to science. That lightning and the electric spark produced by the frictional machines of the time had something in common had been casually conjectured before, but it was Franklin who first went into the matter systematically, giving twelve particulars in which 'electrical fluid' resembled lightning. He also carried out a series of experiments on the effect of sharp points, which were in effect earthed, on discharging electrified bodies in whose neighbourhood they were placed. This led him to propose the form of lightning rod with which his name is so intimately associated—'Would not,' he asks, 'these pointed rods probably draw the electrical fire silently out of a cloud before it came nigh enough to strike, and thereby secure us from that most sudden and terrible mischief?' He suggested an experiment in which a man, standing on an insulating block in a sentry box on a high building, should draw sparks from thunder clouds by means of a pointed rod, an experiment which, following his proposal, was successfully carried out in France.

The experiment with the kite, which so struck the popular imagination that it has ever since been the one achievement generally associated with his name, was done later in Philadelphia. The kite was flown on a twine which, when wetted by the rain, became a conductor—fortunately not a good one—insulated from the hand by a silk ribbon. With his knuckles Franklin drew sparks from a key attached to the twine. The experiment is not always described correctly and was, as it turned out, only a confirmation of what had already been established, following Franklin's reasoning and at his prompting. Franklin, however, has little to complain of in being represented by it in the popular mind when it is considered that Newton is represented by a falling apple.

Franklin's careful studies in static electricity, a very difficult subject for conclusive experiment, on account of the apparently capricious behaviour of the rubbed bodies, led him to enunciate quite clearly that the effect of the friction was to separate two kinds of charges which cancelled one another if brought together. To explain this he put forward his one-fluid theory. According to this, the one electrified body has an excess of fluid and its partner an equal defect, which led him to introduce the terms positive and negative electricity, as used today. There is not, in principle, any great difference between the one-fluid and the two-fluid theory—a negative wealth may equally well be called a debt, something of its own kind—but Franklin's treatment very much clarified the whole subject. He has, in fact, been called the founder of electrical science.

In this connection, the importance of his work on the condenser is often overlooked. The discovery of the Leyden jar, when Franklin was about 40, created a sensation, largely by reason of its power of giving severe physical shocks. Franklin showed the equal and opposite nature of the charges on the two coatings, or, in his own words, that 'the Leyden bottle has no more electrical fire in it when electrified, than before', and further demonstrated that the energy of the bottle resided in the glass. In the course of his work he made the more convenient plane condenser, consisting of a sheet of window glass between thin plates of lead, sometimes known as 'Franklin's pane'. Of such plane condensers he made what he called an electrical battery, sometimes referred to as an electric cascade. The system of charging with one set of connections and discharging with another set is a foreshadowing of Cockcroft and Walton's method of producing high potentials.

Passing reference may be made to work of some importance that he carried out on heat. Franklin was eminently a practical man and, like his countryman Rumford, effected great improvements in the domestic stove, concerning which, as it existed before, he wrote: 'In short, many of the diseases proceeding from colds . . . may be ascribed to strong-drawing chimneys, whereby, in severe weather, a man is scorch'd before, while he's froze behind.' He was the first inventor of bifocal spectacles, improved the musical glasses in an instrument that he called the armonica, designed new forms of various domestic devices, and so on. He, very naturally, prided himself upon the utility of the lightning conductor, and, with this probably in mind, produced one of his epigrammatic passages: 'Nor is it of much importance to us to know the manner in which nature executes her laws: 'tis enough if we know the laws themselves. 'Tis of real use to know that china left in the air unsupported will fall and break, but how it comes to fall, and why it breaks, are matters of speculation. 'Tis a pleasure indeed to know them, but we can preserve our china without it.' His fundamental researches on the behaviour of electric charges clearly show that the pursuit of pure knowledge was for him a pleasure.

Franklin's scientific work, to which, when he sold his printing business for a large sum in 1748, he looked forward to devoting much of his time, actually occupied but a small part of his life. Before the days of his scientific fame he became widely known by his publication 'Poor Richard's Almanack', in which he used to intersperse dry apothegms, many of which have become part of the proverbial sayings in the English language. On account of his personal popularity, his wisdom, his vigour, and his uncommon common sense he was called on to take a leading part in the public life of what were then the American colonies. When, in 1757, a delegate was required to represent the discontents of these colonies, and their causes, Franklin was chosen for the mission. He spent five years in England on this occasion and returned again in 1764 on a further mission of the same nature, which only terminated when, in 1775, there was no prospect of a satisfactory outcome. This is clearly no place for an estimate, however short, of his political activities, but it is agreed that they showed him as upright, incisive yet urbane, and wise, a sage councillor and a far-sighted negotiator. His effort throughout, to which he was moved both by his heart and by his head, was to maintain the union between England and America, as senior and junior partner joined by the honorable regard of each for the rights and interests of the other. His endeavours to effect this object failed, but by no fault of his own. Where Franklin and Chatham were unsuccessful, it is doubtful if any two other men could have succeeded. Franklin's subsequent sojourn in France likewise showed him as a man of learning and a man of the world, welcomed in every rank of society.

It is pleasant to record that Franklin's relations with all the best elements of English life were throughout most cordial. He visited London as an unknown youth and then conceived a warm regard for English ways. His electrical researches were first published in England by the agency of an English friend, and before his next visit he received for them the Copley medal of the Royal Society. When he then came as the official representative of the colonies and as a man famous for his scientific work he at once entered on terms of friendship with outstanding figures of English scientific, social, and political life. He was elected a Fellow of the Royal Society in 1756, and frequently served on the Council of that body. His relations with the then recently founded Royal Society of Arts were equally cordial and intimate. His system of lightning conductors was widely adopted on public buildings and defended by leaders of English science when attacked by a rival after war had broken out. Franklin was, of course, a signatory of the Declaration of Independence, but throughout the period of hostilities his general goodwill remained; he arranged, for instance, for Captain Cook not to be molested by American cruisers, should they meet him on his voyages of exploration. As soon as the war was over, Franklin, who expressed heartfelt satisfaction at its end, received with the approval of George III a copy of Cook's 'Voyages' and a very cordial and conciliatory letter from Sir Joseph Banks, President of the Royal Society, accompanying the gift of a gold medal that had been struck in Cook's honour.

Franklin was a comprehensive and clear-headed genius who achieved outstanding things in pure and applied science, and who, as a man of business, a man of affairs, and a statesman showed the greatest honesty, wisdom, and courage. He was an admirable writer and both in domestic and in national affairs a sage counsellor and a firm leader. He was a wholehearted and practical promotor of international confidence and co-operation. One such is worth many conferences.

The organization within nerve cells

J. Z. YOUNG

In the cytoplasm of all cells there occur several types of particles that are complex molecular aggregates surrounded by membranes. The functions of these are far from clear and it is here suggested that these particles serve as signals by which the nucleus controls the complex operations of the cell. The argument is illustrated by particular reference to nerve cells; these, being large, are especially suitable for study of this intracellular communication system.

Little progress has been made in describing the supramolecular organization within cells, although biochemists from Gowland Hopkins onwards have realised that such a study is necessary [29]. Even the aims and principles appropriate to an inquiry into cellular organization are still not clear, nor what units it should deal with. It has often been suggested that the organization may depend upon a cytoskeleton, presumably of protein, but while this may indeed exist in some cells a more profitable approach is to consider that the organization is not static and that there is constant interchange and communication between parts of the cell. The approach to the problem of intracellular organization suggested here takes account of three considerations: (1) that cell metabolism proceeds in such a manner that life maintains a steady state in spite of external changes; (2) that this circumstance implies a two-way communication between the cell surface and some central system within, presumably, the nucleus; and (3) that much of the material of cells is divided into particles. The characteristic properties of organisms are the result of the fact that they contain certain special groupings of molecules, acquired as a result of past history. No methods are yet available for showing the relations between the many rapidly changing processes in different parts of cells, and this very long sequence of past events. Nevertheless, it is not too early to begin thinking about the problem. Cytology cannot be content to go on indefinitely finding new visible parts of the cell: nor can it be satisfied even by identifying these parts by histochemical methods. What it needs is to discover methods that will describe the organization of cellular events and allow this organization to be compared under different conditions and in various types of cell.

Materials are continually pouring into and out of the cell, and to elucidate the probable course of metabolism of each type of molecule as it enters is one way of discovering the nature of the system as a whole. Life continues because certain sets of substances have been selected and grouped together during the past history of the system. These sets have provided reactions adequate to maintain the steady state in the conditions that have been encountered in the past. They have been built up by a process of trial and error among an enormous number of possible combinations, any that are unstable being rejected. The process is successful in providing systems that are stable under various and varying conditions because of the capacity of carbon to build a vast number of compounds that differ slightly from each other, among which suitable combinations may be selected.

THE CELL AS A COMMUNICATION SYSTEM

The immediate problem is to find ways of describing the combinations and of showing how they direct the course of metabolism. The method of selection of the particular sets of molecules effective in any organism at any time is in the last resort that of natural selection: it seems likely, therefore, that some form of stochastic treatment may be useful for describing cellular organization.

It is not unrealistic to compare a cell or an organism and its surroundings with a communication channel. The value of the comparison derives from the fact that both situations deal with the limitations upon future behaviour imposed by sets of combinations that have been selected in the past. Communication theory deals with the way in which 'decisions' are influenced by 'information'. The information is transmitted by choosing from a prearranged code the combination of symbols that is appropriate to a particular environmental situation. After suitable transmission this information controls the behaviour of the receiver in such a way that it makes a correct adjustment to the situation. If the information is sent from a peripheral source to some controlling centre, the response of the latter may consist in the transmission of instructions to the periphery, according to the principle of operations embodied in the control centre.

The concept of 'receptors' at the cell surface is already quite familiar to biochemists and pharmacologists. Events occurring in the immediate neighbourhood of an organism or cell act as selectors among a limited set of chemical operations that are possible near the surface. This is comparable to selection of certain words from a language to form a message. The possible cell reactions have been preselected, like the words, to suit certain likely external events. The changes near the surface of the cell influence reactions further in; these follow rules of which we are almost wholly ignorant, but presumably they too depend on the previously selected arrangements. Thus we can consider that 'information' is transmitted inwards and ultimately reaches the nucleus, which contains the ultimate controlling agency and is the most constant component in the cell.

The mean amount of deoxyribose polynucleotides (DNA) in the nuclei of all the somatic tissues of any one species is the same (table I). The amount in the sperm nuclei is half that in the somatic nuclei. In a tissue such as rat liver, where the content is high, some of the cells contain more than one chromosome complement [13].

TABLE I

Mean content of DNA per cell ($10^{-12}g$)

	Rat	*Fowl*	*Ox*	*Frog*	*Toad*	*Carp*
Liver	9·4	2·6	6·4	15·7	—	3·3
Kidney	6·7	2·3	—	—	—	—
Spleen	6·5	2·6	—	—	—	—
Lung	6·7	—	—	—	—	—
Leucocytes ..	6·6	—	—	—	—	—
Erythrocytes ..	—	2·6	—	15·0	7·3	3·5
Heart	6·5	2·5	—	—	—	—
Pancreas ..	7·3	2·7	—	—	—	—
Brain	—	2·3	—	—	—	—
Muscle	—	2·5	—	—	—	—
Sperm	—	1·3	2·8	—	3·7	1·6

The relative constancy of this component in the cell is of the greatest interest, since we know from many facts that the nucleus provides the central control system that ensures the constancy of each type of living organism. Nuclear behaviour during cell division shows elaborate mechanisms by which the constancy is preserved in copying, the material being arranged in distinct units, the genes, regularly aligned on discrete chromosomes. During the formation of the germ cells there is a meticulous arrangement for halving this material and ensuring that the next generation starts with the standard amount of nuclear material, with one copy of each part of it derived from each parent. The male contribution consists of little else besides these nucleoproteins. Thus the nucleus provides the instructions that ultimately control the metabolism of every cell.

The operation of the control system must consist essentially in sending outwards into the cell communications that constitute the instructions. According to these instructions, 'decisions' are made between one course of metabolism and another. From the environment, meanwhile, information is continually transmitted inwards through the cytoplasm, ultimately presumably influencing the instructions that are sent out by the control system of the nucleus. Except in rare cases (mutations) this information does not alter the basic properties of the control system itself, which remains as the determinant of the characteristic behaviour of each cell of the species.

THE SIGNIFICANCE OF PARTICLES IN THE CELL

It is thus easy to see that a general comparison can be made between a cell and a two-way communication system. If this was merely an entertaining *façon de parler* it would be of little value, but there are indications that it could be made more precise and may provide a method by which we could describe the elusive organization of the cell. One of the most striking facts of cytology is that much of the cellular material is aggregated into particles of various types, which are found, varying somewhat in detail, in all animal and plant cells. The chromosomes, with their subdivision into chromomeres and bands, are the most familiar example. In the cytoplasm there are bodies of various sorts, mitochondria, lipochondria (Golgi substances), endoplasmic reticulum, and microsomes, which will presently be described. Cytologists have long recognized that these bodies are not composed of a single chemical species but are quite complicated aggregates. For example, mitochondria are complex structures containing proteins and phosphatides and are the bearers of a large range of enzymes [33].

Perhaps the fact that these complex aggregates are arranged as discrete bodies is one of the most significant things about them as fundamental components of life-systems that maintain stable states.

Communication theorists are familiar with the fact that if a message is to be transmitted along a channel and remain stable it must be recorded in the form of discontinuous units [24, 34]. Any attempt to transmit a representation of a complicated pattern of events by a continuous process of making exact copies is bound to fail because of the errors of copying due to noise, which are cumulative. The solution that is adopted for communication is to code the message into discrete symbols, each of which is transmitted and copied completely or not at all. Words are of this nature, as of course are the dots and dashes of the morse code or the nerve impulses that constitute the code of the nervous system.

It may be that we see here the significance of the fact that cells contain discrete granular aggregates. Each such cell particle may be compared to a signal. It has a definite significance as the bearer of what we may call conventional meaning, in the sense that it has been built up in the past by selection of materials appropriate to produce a particular effect under suitable conditions. Each granule or particle, like a word, is built up until it is complete and then operates as a unit, able to elicit a certain metabolic response according to the conditions that it meets. Being composed of such units the cell is able to transmit a stable pattern of behaviour.

ADVANTAGES OF MICROSCOPY FOR THE STUDY OF CELL ORGANIZATION

If this approach has any value there is a worthwhile task for cytologists in studying these discrete components of the cells, their mode of formation, frequency, and distribution. Unfortunately suitable quantitative data are as yet few, and they will have to be collected with these specific objectives in mind. The light- and electron-microscopes are fortunately very suitable instruments for this purpose, though they suffer from some severe limitations. With them it is difficult to identify the chemical composition of the particles, though histochemistry has made great advances in this respect. The great advantage of microscopes is that they provide a high degree of resolution in space. Cellular particles range from a few angstroms in diameter upwards, and their relations and distribution in the cell can hardly be studied by methods of isolation, valuable though these methods may be for other purposes.

The large amount of water in living tissues makes microscopy difficult, since it must be removed to obtain high resolution. This limitation has deterred many who hanker after 'study of the living cell'. However, if the procedures of preparation are properly arranged this need not introduce any unusual difficulty of principle. Perhaps the most severe difficulty of work at high optical resolution is that the cell can be studied only at one instant. This poor resolution in time can be avoided only by laborious experiments in which series of samples are fixed.

NEURONS AS MATERIALS FOR THE STUDY OF TRANSMISSION WITHIN CELLS

Neurons are suitable in many ways for the study of the organization and communication within cells. They are large and internally differentiated into distinct parts (figure 2). It is easy to show that all parts of a neuron are under the control of the nucleus, lying in the nerve-cell body. Any part that is cut off from the cell body begins to show degenerative changes within a few hours. Throughout life, therefore, something that prevents degeneration must be transmitted to the distant parts of the cell. There is also transmission in the reverse direction, for after a nerve fibre has been severed changes occur within the cell body, which begins an active process of protein synthesis, allowing regeneration of the nerve fibre (p. 8). Indeed, the synthetic system within the cell body changes its operations to suit the functional activity that has occurred and the supply of raw materials provided. Further evidence of communication between different parts of a neuron is that when a young nerve fibre makes connection with a muscle the whole fibre is stimulated to grow [1]. The problem is to identify the transmission system involved and to discover whether it operates by means of any discrete units or signals.

THE NUCLEUS

The nucleus contains a number of highly specific particles, the genes, but in adult neurons no visible sign of these can be detected with either the light- or the electron-microscope. The nucleic acids in the nucleus give it the characteristic property of staining with basic dyes (figures 3–6, 27, and 29). The stain is not uniform, and various types of relatively large bodies are found. In neurons of cephalopod molluscs such as squid, cuttlefish, or octopus there is usually a deeply basophil nucleolus and one or more less basophil bodies, the plasmosomes. There are also many smaller basophil granules, and a nuclear sap that is unresolved by the light microscope. The nucleolus is a constituent of nearly all nuclei.

Specific staining methods, and the fact that it absorbs ultra-violet light at 2750 Å, show that it contains a large amount of ribosepolynucleotides (RNA). The nucleoli become enlarged in any cell that is undergoing rapid protein synthesis, for example in nerve cells that are regenerating after their nerve fibre has been severed. It is suggested that the nucleolus is the seat of collection of RNA during its synthesis from, or under the control of, DNA [7, 12].

In the sea hare, *Aplysia*, the nucleolus contains one or more bodies with a refractive index very different from that of the rest. These can be seen in both living and fixed cells (figures 7–10 and 12), but their nature is not known. The details of the organization of the nucleolus remain obscure. In electron micrographs it may appear to contain numerous spherical areas of lesser density (figure 1), but these may be artifacts, and the nucleolus has been reported to contain masses of filaments, sometimes with granules attached [5].

Although in most adult nuclei the chromosomes are not visible, the 'nuclear sap' is certainly not a homogeneous material. In mammalian neurons there are electron-opaque bodies of various sizes. Some of these are finely granular and may show signs of regular arrangements of the granules. In addition the nuclear sap contains a number of electron-opaque spheres of diameter up to 200 mμ, which may be the precursors of lipochondria (p. 10). Mention must also be made of the nucleolar satellite, a basophil body containing DNA, which is larger in the neurons of female than male mammals and therefore presumably represents the sex chromatin derived from the X chromosomes [25].

The boundary between nucleus and cytoplasm is marked by a membrane, up to 40 mμ thick, which must be the seat of important processes regulating the passage of materials inwards and outwards. This is seen in a living cell in figure 13 and in electron micrographs in figures 1 and 2. The details of its composition are still not known. It contains two dense layers separated by a lighter one up to 20 mμ in thickness. It is not equally dense at all points, and the two layers may be joined at intervals by what may be holes or channels of different permeability (figure 2) [27, 18]. There is little doubt that quite large particles pass through the membrane, but there is little evidence as to whether they go inwards as well as outwards or what controls their formation. The main cytoplasmic components to be described below—mitochondria, ergastoplasm, and lipochondria—may all occur close to the outer surface of the nuclear membrane (figure 1), and it would be extremely interesting to know whether they are formed there or pass through the membrane.

Our knowledge of visible nuclear structure at present provides hints, but few facts, as to the way it receives information from the cytoplasm and transmits instructions back to it. The most definite clue is that the production of ribonucleotides is increased in the nucleolus whenever a cell is stimulated to protein synthesis. The presumption is that the RNA passes outwards through the nuclear membrane to form the basis of the synthetic processes in the cytoplasm. What we need to know is whether this transmission takes place as a continuous flow or in the form of discrete particles. During the phase of regeneration of a nerve cell after severance of its axon, new RNA probably appears at the nuclear surface (see figure 6). The nuclear membrane then shows folds and thickening [18], and vesicles may be seen actually within these folds and are perhaps formed there. Masses of electron-opaque granules have been seen on both sides of the nuclear membrane, suggesting that transfer takes place in the form of discrete packets or granules. Opinions as to the nature of these bodies formed at the nuclear surface vary; they may be ergastoplasm [14], defined later, or mitochondria [18, 9]. There are also suggestions that lipochondria may be formed at the nuclear surface (see below). There are, therefore, indications that communication between nucleus and cytoplasm is in the form of signals consisting of organized aggregates.

CYTOPLASMIC NUCLEIC ACIDS

It is characteristic of nerve cells that their cytoplasm contains large masses of basophil material called, after its discoverer, the Nissl substance. It is now known that the material includes ribonucleotides and that these are arranged in units of specific structure, to which the name endoplasmic reticulum or ergastoplasm has been given [27].

The Nissl substance is seen with the light-microscope as masses of deeply basophil material, often divided into clumps or bodies by clearer spaces (figures 3–6 and 41). Electron microscopy shows that the Nissl bodies are aggregates of masses of narrow tubes, which are often, but not always, covered with fine granules (figure 1*b*). The tubes may take different forms as flattened cisternae, tubules, and vesicles, making an elaborate branching and intercommunicating system. The limiting

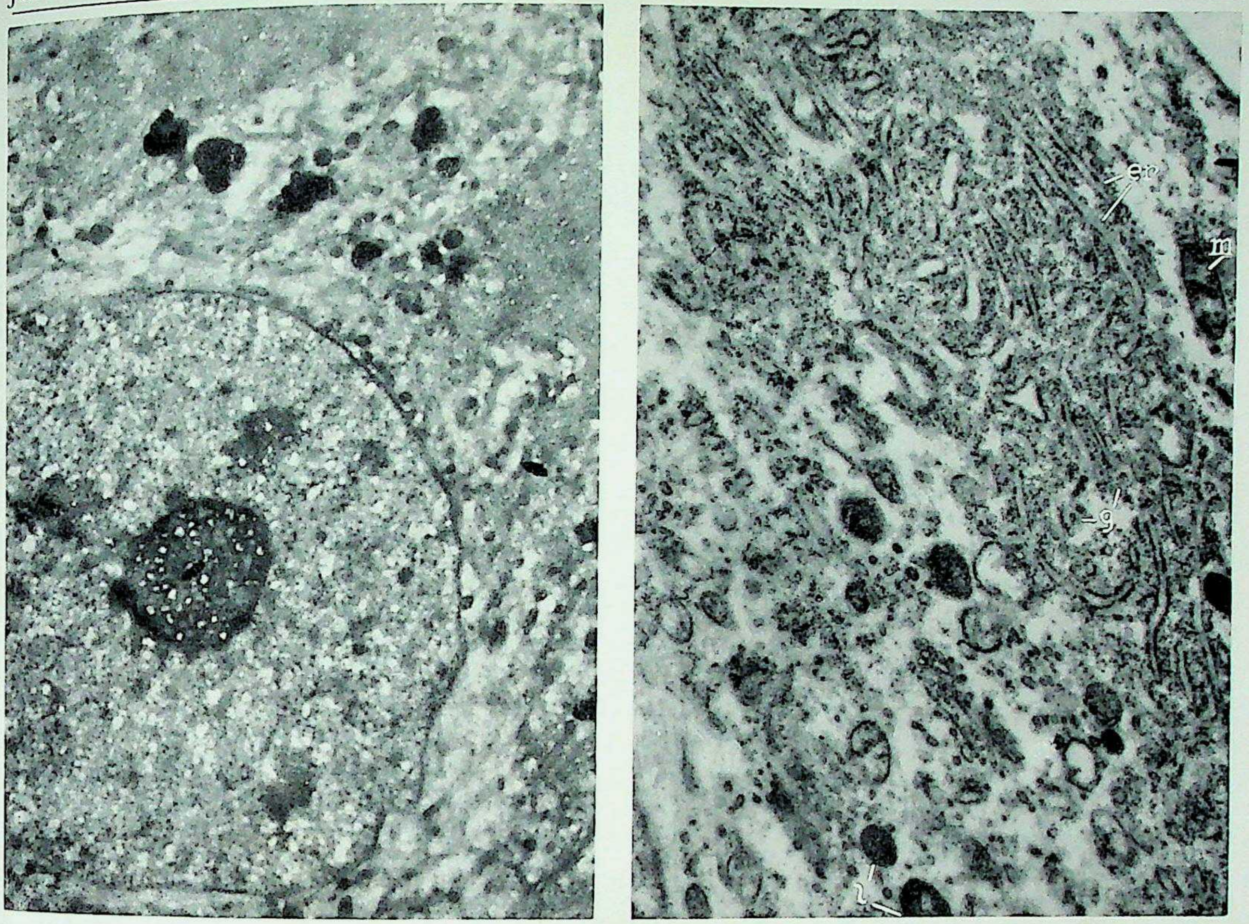


FIGURE 1 – (a) (*left*) *Low-power electron micrograph of nucleus and nearby regions of a nerve cell of the spinal cord of the rabbit. Fixed osmium tetroxide and photographed without removal of the embedding plastic. There is a large nucleolus with chromatin masses* (*possibly DNA*) *near it. The nuclear sap contains many granules, including relatively large opaque spheres* (*possibly lipochondria precursors*). *Outside the nuclear membrane are lipochondria, mitochondria, and Nissl substance, the last not showing its internal organization* (× 10 000). (b) (*right*) *Portion of cytoplasm of a cat's neuron, showing vesicles of endoplasmic reticulum* (*er*) *with granules* (*microsomes*) *attached* (*g*). *The mitochondria* (*m*) *show internal division by septae; l, lipochondria.* (*From Palay and Palede* [27].) (× 24 000)

membranes are 6–7 mμ thick and the lumina vary from 30 to 50 mμ, with wider dilatations. The granules attached to these tubules are 10–30 mμ in diameter and are commonly arranged in clusters or rosettes of five or seven together, but also occur singly or in rows. The granules are comparable to the microsomes, basophil particles that can be isolated from liver and other tissues by centrifugation [10]. In liver cells this fraction has been shown to contain proteolytic enzymes.

Proceeding away from the nucleus, the Nissl granules become in general smaller and formed of less and less regularly arranged reticulum. Approaching the outside of the cell or a dendrite, the reticulum becomes broken up into smaller and smaller components, and in the peripheral parts of the cell it appears as a very loose network or as separate tubules, with or without attached granules. In the preparations shown in figure 41 removal of the plastic has distorted the individual elements of the reticulum so that they appear as threads with granules attached.

The distribution of this material through the cell can be approximately followed by light-microscopy by studying the basophilia. The cytoplasm of the cell body stains intensely with basic dyes, showing the Nissl granules. Proceeding away from the cell body along either axons or dendrites the intensity of staining diminishes, rapidly at first, later more slowly. No measures of this change are available, but the difference between material close to and away from the cell body is shown clearly where the distal end of one cell comes into close contact with the more proximal part of another one at a synapse (figures 14 and 36).

All this evidence is compatible with the suggestion that the endoplasmic reticulum and its ribonucleic acids are concerned in the synthesis of material, perhaps protein, under the influence of the nucleus. Specific ribonucleoproteins may be produced within the cell body and then passed down the processes of the nerve to conduct further synthesis there. A nerve fibre whose axon is 10 μ in diameter may be a metre or more long, and it is difficult to imagine how transport could be effected along such a very narrow channel. Nevertheless there is reason to think that it does take place. Active movement along axons is readily seen in tissue culture, and there is a considerable body of evidence suggesting transport away from the cell body along nerve fibres [37, 41]. Every part of the nerve cell depends upon the cell body, and any part that is cut off begins to degenerate and breaks up within a few days. There must therefore be some form of transmission along the nerve fibre responsible for the maintenance of the organization. Nerve fibres very readily assume an unduloid outline (figure 16), and it has been suggested that the material of which they are composed has liquid properties and tends to break up as a result of surface tension effects [41]. Pressure within the fibre would prevent this break-up, and there is probably also a continual transfer of material along the fibre. If nerve cells are cut out and left completely isolated from the body, signs of the movement of the Nissl substance from the cell body to the axon can sometimes be seen in the course of a few hours (figure 17).

The cytoplasmic nucleotides readily change their activity in response to changes in the nerve fibre. If the axon is severed the Nissl substance first reduces in amount (figure 5, chromatolysis) and is then re-formed, at or near the surface of the nucleus (figure 6). Moreover, if a nerve cell is made continuously active for some time the cytoplasmic ribonucleotides increase [20]. There must therefore be some agency by which transmission from peripheral parts of the cell to the centre takes place.

THE LIPOCHONDRIA

The system known as the Golgi apparatus contains various distinct substances. This can be clearly seen in the neurons of molluscs, which will be considered here [40]. The Golgi bodies consist primarily of spheres, the lipochondria [3], which contain phosphatide and other material. They are coloured yellow in some cells (see later) and stain intravitally with neutral red, methylene blue, and other dyes. Associated with these bodies are other substances, and the whole system may adopt net-like or other appearances after fixation, especially since the lipochondria are very sensitive to changes in osmotic pressure (see below).

If thin slices of a ganglion of an octopus or cuttlefish are examined in sea water there are seen to be numerous colourless or faintly yellow spheres in the region around the nucleus. These bodies can be stained with neutral red (figure 18), a dye that sometimes colours structures pre-formed in the cells, though it may also set up reactions that lead to the production of bodies that were not previously present. In these nerve cells of cephalopods it is possible to see the unstained bodies and to watch the appearance of colour in them when a dilute solution of neutral red is run under the coverslip. The stained bodies show interesting changes as the tonicity of the medium is varied. In hypotonic solutions they swell and in hypertonic solutions they shrink. The process is reversible, and a single droplet can be watched passing through several complete cycles (figures 19–25). When shrunken the surface often becomes crumpled (figures 22 and 24) and the droplet may assume various forms, some of them suggesting that the plasmolysis has led to the drawing away of an inner compartment of the drop, leaving the original outline faintly apparent (figures 20 and 24). Such crescent-like appearances are difficult to interpret except on the assumption that the droplet is covered by two membranes which can be separated [40, 42]. There is no evidence from electron microscopy as to whether double layers exist around these bodies in molluscan nerve cells. Other cell constituents have been shown to carry double membranes, in particular the mitochondria [11, 26], which have also been shown to swell and shrink with changes in the tonicity of the medium [10, 35, 32].

The properties of such intracellular membranes are obviously of outstanding interest, since they represent sites at which metabolic processes are controlled. It has often been assumed that the main regulatory surfaces of the cell are the outer cell membrane and the nuclear membrane. The situation is much more complicated if we have to consider the presence of several other types of specific surface, such as those of the endoplasmic reticulum, mitochondria, and lipochondria. For example, many calculations of the position of free water in the body have assumed that osmotic interchanges take place at the cell surface. The

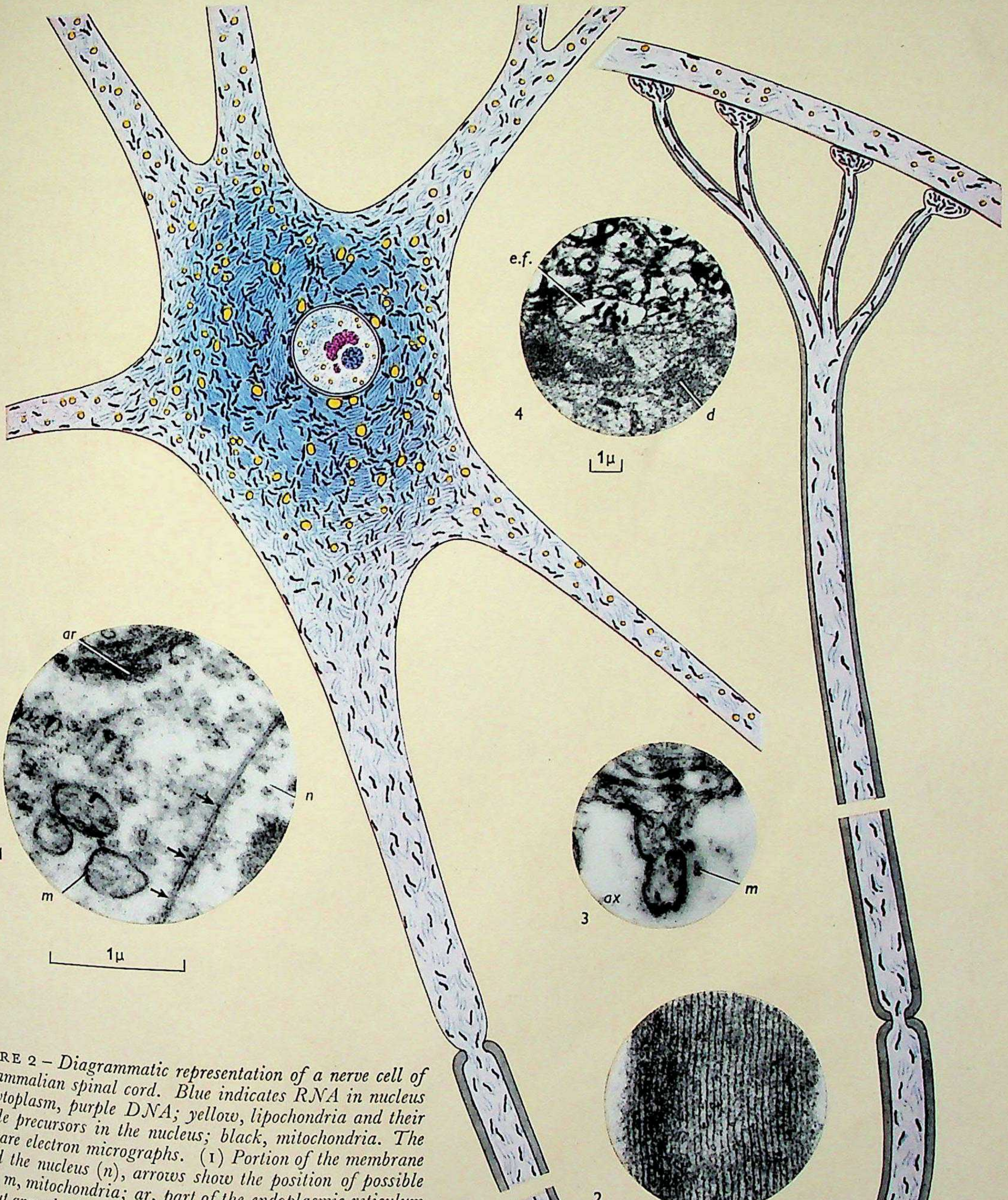


FIGURE 2 – *Diagrammatic representation of a nerve cell of the mammalian spinal cord. Blue indicates RNA in nucleus and cytoplasm, purple DNA; yellow, lipochondria and their possible precursors in the nucleus; black, mitochondria. The insets are electron micrographs.* (1) *Portion of the membrane around the nucleus* (*n*), *arrows show the position of possible pores; m, mitochondria; ar, part of the endoplasmic reticulum without granules* (*from Palay and Palade*). (2) *Myelin sheath, showing lamellae* (*from Sjöstrand*). (3) *Surface of an axon of a lobster, showing* (*above*) *layers within the Schwann cell and* (*below*) *the formation of a body* (*perhaps mitochondrion*) *m, by invagination into the axoplasm* (*ax*) (*from Geren and Schmitt*). (4) *Portion of a dendrite* (*d*) *of a mammalian neuron outside which is a terminal end foot* (*e.f.*). *Fine nerve fibres with their sheaths are seen at the top of the picture.*

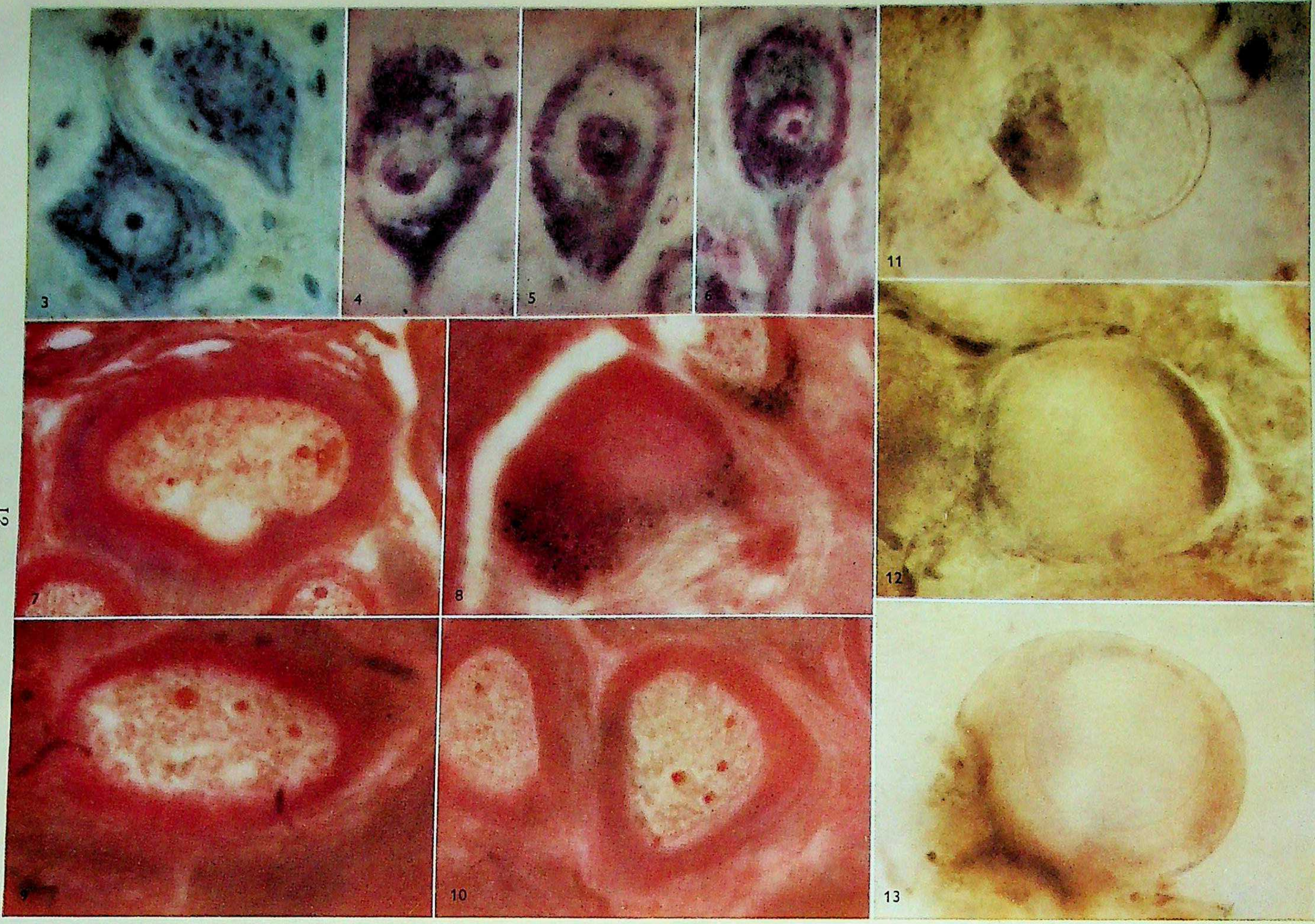


FIGURE 3 – *Cells of spinal cord of cat. This and figures 4–6 were fixed in Carnoy's fluid and stained toluidin blue, showing the basophil material (mainly nucleotides) in nucleus and cytoplasm.* FIGURE 4 – *Normal nerve cell of octopus.* FIGURE 5 – *Octopus nerve cell whose axon was cut seven days previously, showing disappearance of cytoplasmic nucleotides.* FIGURE 6 – *Similar cell 17 days after axon was cut. The nucleotides are reappearing in the cytoplasm, and are especially abundant around the nucleus.* FIGURES 7–10 – *Nerve cells of the sea hare* (Aplysia)*; fixed in a chrome-osmium acetic mixture and stained with safranin. The basophil nucleoli contain unstained refringent bodies. The cytoplasmic nucleotides appear as a reddish ring around the nucleus. The lipochondria are stained black by the osmium (especially in figure* 8). FIGURES 11–13 – *Living nerve cells of the sea hare, examined in sea water. The large nucleus contains fine granules, and in figure* 12 *a nucleolus with refringent centre is seen. In the cytoplasm are masses of lipochondria containing yellow pigment.*

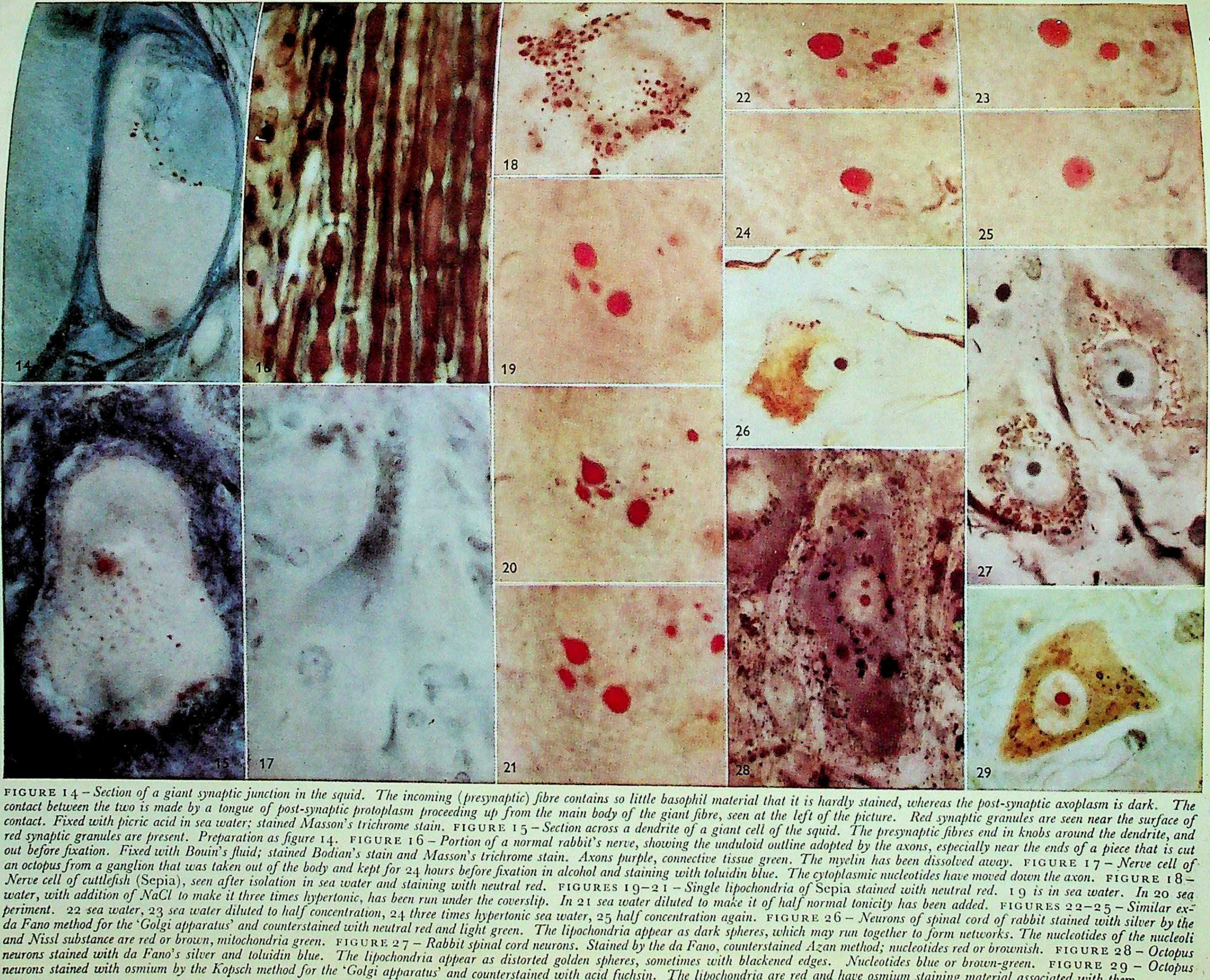
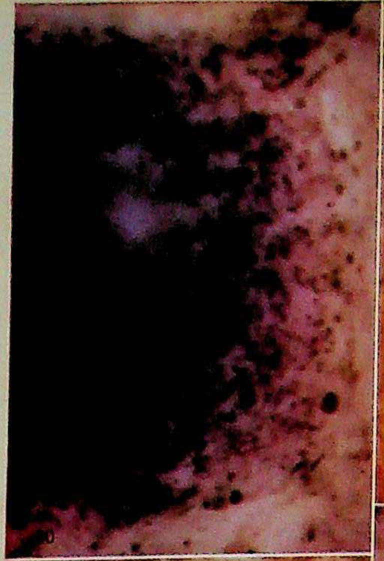
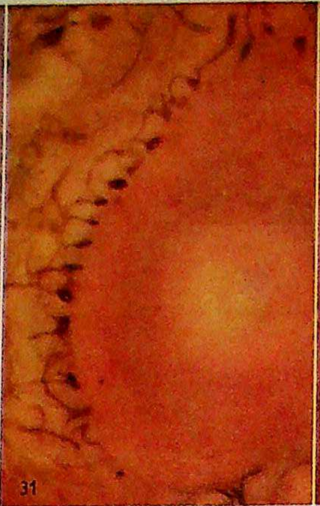


FIGURE 14 – *Section of a giant synaptic junction in the squid. The incoming (presynaptic) fibre contains so little basophil material that it is hardly stained, whereas the post-synaptic axoplasm is dark. The contact between the two is made by a tongue of post-synaptic protoplasm proceeding up from the main body of the giant fibre, seen at the left of the picture. Red synaptic granules are seen near the surface of contact. Fixed with picric acid in sea water; stained Masson's trichrome stain.* FIGURE 15 – *Section across a dendrite of a giant cell of the squid. The presynaptic fibres end in knobs around the dendrite, and red synaptic granules are present. Preparation as figure* 14. FIGURE 16 – *Portion of a normal rabbit's nerve, showing the unduloid outline adopted by the axons, especially near the ends of a piece that is cut out before fixation. Fixed with Bouin's fluid; stained Bodian's stain and Masson's trichrome stain. Axons purple, connective tissue green. The myelin has been dissolved away.* FIGURE 17 – *Nerve cell of an octopus from a ganglion that was taken out of the body and kept for* 24 *hours before fixation in alcohol and staining with toluidin blue. The cytoplasmic nucleotides have moved down the axon.* FIGURE 18 – *Nerve cell of cuttlefish* (Sepia), *seen after isolation in sea water and staining with neutral red.* FIGURES 19–21 – *Single lipochondria of* Sepia *stained with neutral red.* 19 *is in sea water. In* 20 *sea water, with addition of NaCl to make it three times hypertonic, has been run under the coverslip. In* 21 *sea water diluted to make it of half normal tonicity has been added.* FIGURES 22–25 – *Similar experiment.* 22 *sea water,* 23 *sea water diluted to half concentration,* 24 *three times hypertonic sea water,* 25 *half concentration again.* FIGURE 26 – *Neurons of spinal cord of rabbit stained with silver by the da Fano method for the 'Golgi apparatus' and counterstained with neutral red and light green. The lipochondria appear as dark spheres, which may run together to form networks. The nucleotides of the nucleoli and Nissl substance are red or brown, mitochondria green.* FIGURE 27 – *Rabbit spinal cord neurons. Stained by the da Fano, counterstained Azan method; nucleotides red or brownish.* FIGURE 28 – *Octopus neurons stained with da Fano's silver and toluidin blue. The lipochondria appear as distorted golden spheres, sometimes with blackened edges. Nucleotides blue or brown-green.* FIGURE 29 – *Octopus neurons stained with osmium by the Kopsch method for the 'Golgi apparatus' and counterstained with acid fuchsin. The lipochondria are red and have osmium staining material associated with them.*





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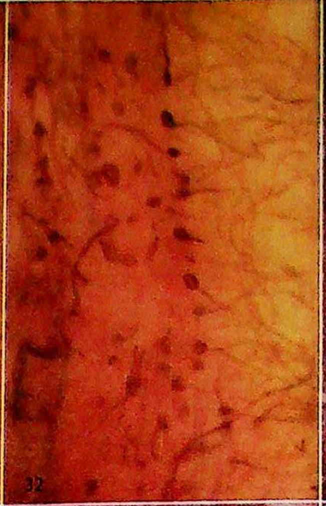

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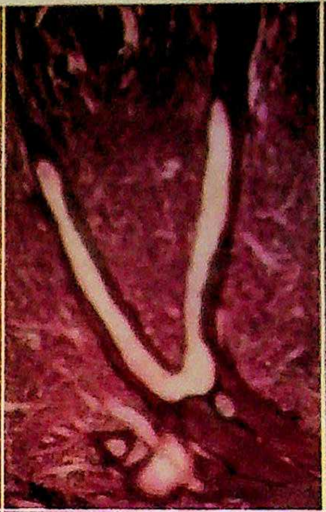

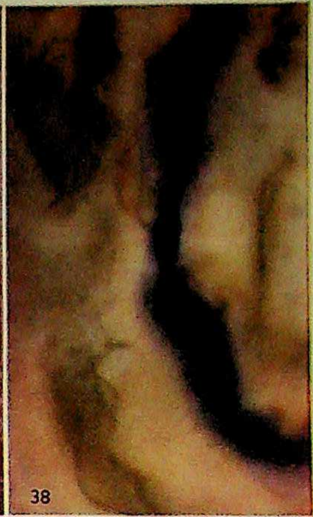

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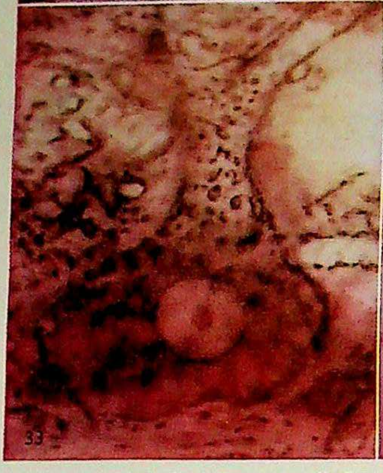

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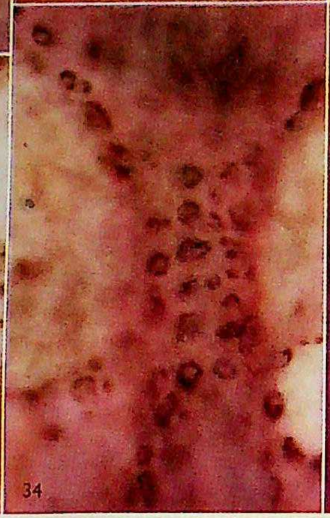

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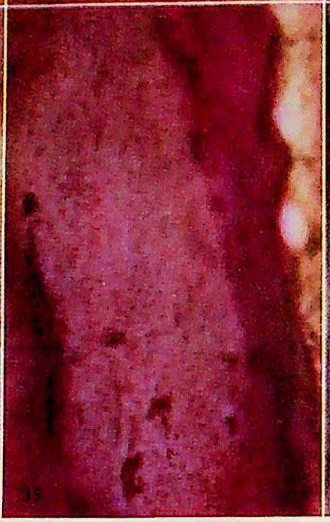

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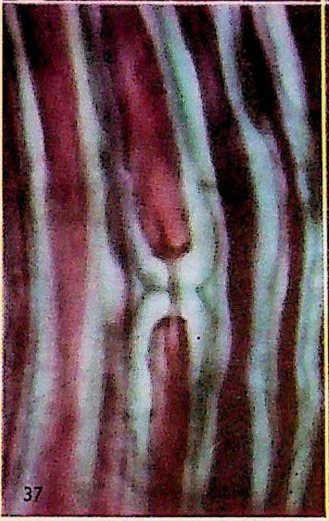

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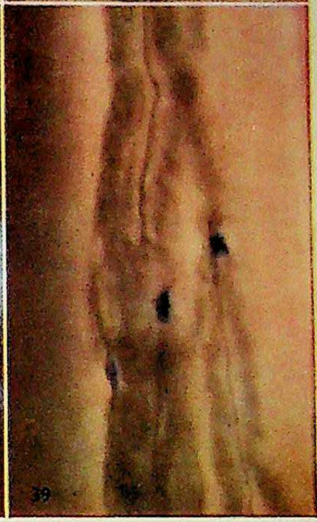

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FIGURE 30 – *Mitochondria in nerve cell of spinal cord of a rabbit. Fixed formalin, post-chromed embedded in Carbowax and stained by a silver method.* FIGURES 31 AND 32 – *Synaptic end feet in the spinal cord of the rabbit. Fixed formalin and stained by Cajal's method, embedded in Carbowax.* FIGURES 33 AND 34 – *Synaptic end feet stained to show the mitochondria they contain. Fixed formalin, post-chromed, embedded Carbowax, and stained with a modified Bielschowsky's silver stain.* FIGURE 35 – *Longitudinal section of post-synaptic portion of giant nerve fibre of squid (see figure 36). 'Neurofibrils' are seen in the axoplasm. The axoplasm immediately below the synapse contains synaptic granules less basophil than the rest of the material. Fixed picroformol in sea water; Mallory's stain.* FIGURE 36 – *Low-power view of giant synapse in the squid, prepared as figure 35. The presynaptic fibres are little stained because they are poor in nucleoproteins (p. 9). They are seen lying on top of the more darkly staining part, synaptic giant fibres.* FIGURE 37 – *Node of Ranvier in rabbit's nerves. Staining: Bouin, Bodian, Mallory. Axons purple, collagen green, myelin dissolved away.* FIGURES 38 AND 39 – *Nerve fibres of a frog, stained supravitally with methylene blue, which enters only at the nodes. Myelin lightly stained brown with osmium tetroxide.*

demonstration that they occur within the cell makes it unnecessary to postulate the presence of large volumes of extracellular water in the tissues [22].

The classical means for revealing the materials of the Golgi apparatus involve fixation and staining with osmium or silver (figures 27 to 29). The relation of the networks shown by these methods to the bodies stained with neutral red has been much discussed. M. Parat [28] and others considered that the Golgi apparatus seen after fixation consisted simply of the distorted neutral red vacuoles. This view is certainly not wholly correct, because other material may be associated with the lipochondria. The situation differs in different cell types; moreover the effect of neutral red on the cells has to be taken into consideration. In the cephalopod neurons that we are now considering, neutral red bodies are certainly closely associated with the structures revealed after fixation by the Golgi methods. After such procedures the spherical bodies can be seen around the nucleus, usually lightly stained with osmium or silver (figures 27 and 28). Sometimes the bodies are crescentic, presumably as a result of distortion during fixation. The bodies at greater distance from the nucleus are often larger, as in the living cell, and may sometimes be seen to run together to make a network.

These bodies are not always the most deeply coloured objects seen after staining with these metals. Darker granules are found in the same regions, but between, and often on the surface of, the larger neutral red bodies. By suitable staining it is possible to colour the larger bodies with acid fuchsin, showing that they are distinct from the granules stained with metal (figure 28).

The fact that the Golgi apparatus includes a more darkly staining and a lighter component has long been known, not only in this case but also in others. Histochemical tests have now shown that various other components may be present, for instance a mucopolysaccharide [8]. Evidently, then, we are dealing with an aggregate of materials of some complexity, and such multiplicity of parts would be in keeping with the conception that the Golgi materials constitute another of the fundamental molecular groupings by which the stability of cell organization is ensured. The problem of naming this constituent remains difficult. Spheres of partly lipid or phosphatide nature are a common feature of the material and a strong case can be made for referring to these as lipochondria [3], but this name tends to obscure the chemical complexity that these aggregates possess in many, perhaps all, cases. The term Golgi complex expresses this not inappropriately, but has an unfortunately mysterious ring.

Material of this type is probably present in all animal and plant cells, but it is still not easy to make statements about the significance of the various forms that it takes. In the neurons of some molluscs the lipochondria in the perinuclear region show a brilliant yellow or orange colour (figures 11–13) [23, 36]. Red haemoprotein granules are also present. The spheres described above in cephalopod ganglia may show a faintly yellow colour. The strongly yellow bodies take up neutral red, as do the comparable less coloured cephalopod granules. They also stain lightly with osmium tetroxide (figure 8) and have the capacity of swelling and shrinking reversibly with changes in the tonicity of the medium. There is therefore every reason to think that in all molluscan neurons the lipochondria contain some yellow pigment. The pigment is soluble in alcohol and may be a carotenoid [6]. Irradiation of dark-adapted neurons of *Aplysia* with light of the wavelength absorbed by the pigment increases their reaction time [2]. This tells little of the normal function of lipochondria, but suggests a connection between the photochemical processes in the eye, which involve carotenoid derivatives, and more general cellular metabolism.

There have been many speculations as to the function of the Golgi materials, mostly connected with the fact that changes are seen in them during certain phases of synthesis by the cell and that some secretory granules arise in connection with them. For example, L. G. Worley and E. K. Worley [38] showed that the individual bodies grow and can rapidly produce particles of either protein or fatty material in developing larvae. A further clue is that there are oxidizing systems associated with these granules [40], and this suggests a connection with the possible capacity of carotenoids as part of a redox system. If synthetic enzymes are localized in the lipochondria they would presumably need associated redox systems. It may be that the structure of each lipochondrion is such as to allow synthetic enzymes to work in one direction by assuring segregation of the products of reaction within the vacuole.

Interesting changes are seen in the Golgi materials of nerve cells after severance of the axon. Great quantities of very small lipochondria appear near the nucleus (figure 26). These may be connected with the process of synthesis that

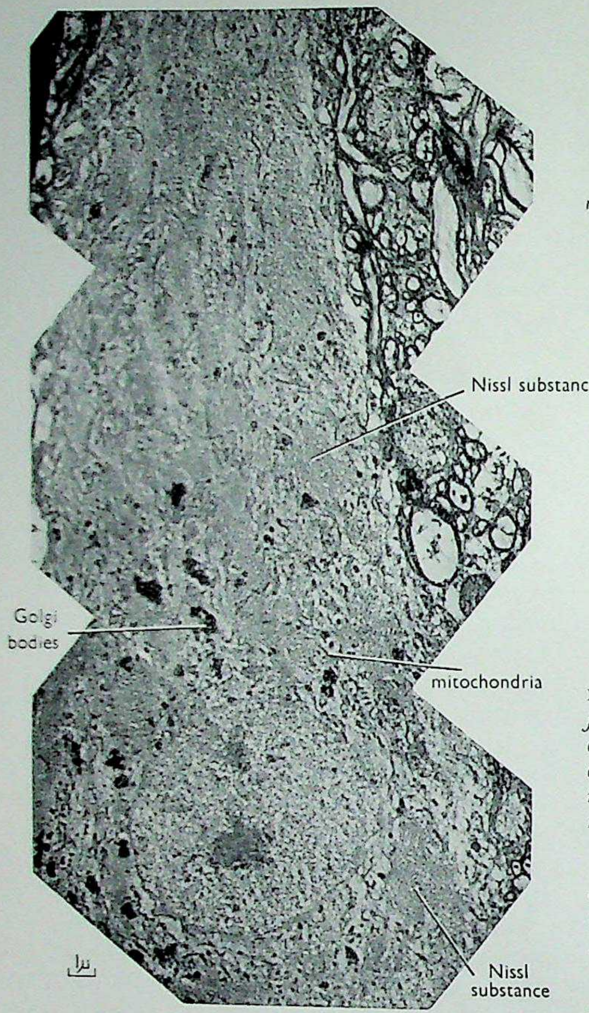

FIGURE 40 – *Electron micrograph of part of the cell body and a dendrite from the spinal cord of a rabbit.*

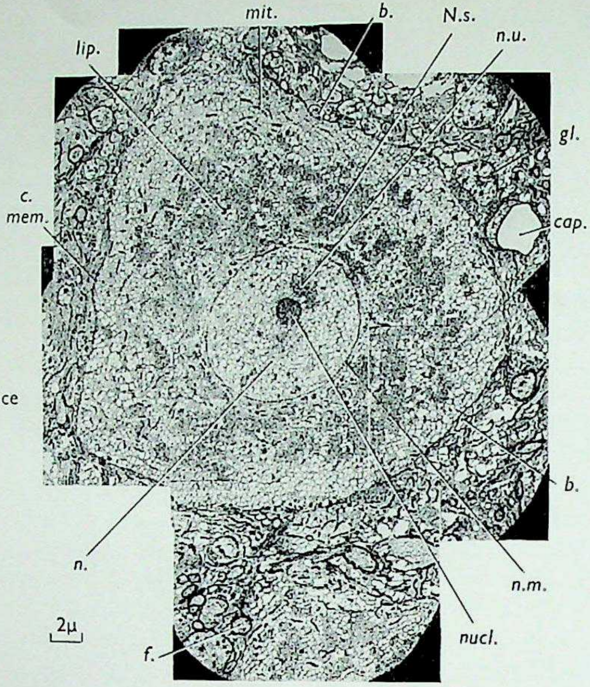

FIGURE 41 – *Drawing of electron micrograph of nerve cell from the spinal cord of the rabbit. b., bouton; cap., capillary; c. mem., cell membrane; f., nerve fibre; gl., glia; lip., lipochondria; mit., mitochondria; n., nuclear sap; n.m., nuclear membrane; N.s., Nissl substance; n.u., DNA; nucl., nucleolus.*

accompanies regeneration of the nerve fibre. Unfortunately it is not known how these particles arise.

The condition of the Golgi material in vertebrate nerve cells remains doubtful. It was in these cells that Golgi first described his network, but it is probable that this form is an artifact of fixation, and many of the bodies stained with these methods are spheres (figure 29). Electron microscopy shows the lipochondria as electron-opaque spheres after osmium fixation (figures 1, 40, and 41). Their origin or method of formation is not known, but they are similar to the smaller electron-opaque spheres that are seen within the nucleus. Some preparations suggest that the latter may pass through the nuclear membrane. There have been frequent suggestions that lipochondria are produced by the nucleus, for instance in the formation of yolk [39]. It is therefore a reasonable hypothesis that they are organized particles produced by the nucleus under the ultimate control of the genes.

The lipochondria are largest and most numerous in the region of the cell body around the nucleus. They may be associated with endoplasmic reticulum, indeed occasionally they lie at the centre of concentric lamellae of the latter. They extend into dendrites, but are smaller and less numerous there, and they are not found in the axon. This distribution is in agreement with the suggestion that they are particles produced by the nucleus and capable of initiating particular synthetic activities in the cytoplasm.

MITOCHONDRIA

These bodies, usually rod-like, are the best known of all the discrete cytoplasmic constituents. They carry a large part of the cytochrome oxidase system of cells, and many other enzymes beside [33]. They are certainly actively concerned in many metabolic processes. There is still little information about the origin or growth of mitochondria or how the reactions they ensure are controlled. The mitochondria in nerve and other cells contain a system of internal septae (figures 1 and 2). They are present in all parts of the cell but at varying densities. They are plentiful in the region surrounding the nucleus (figure 30) and interspersed between the large granules of Nissl substance in the cell body. At the edge of the cell body, where the endoplasmic reticulum appears as separate vesicles, the mitochondria are numerous and are often in close contact with elements of the reticulum. They are also numerous in the dendrites. They are less abundant in the substance of the axon, where they lie as very elongated rods along the axis of the fibre. Mitochondria are again very abundant in the finest terminations of the axon, in the terminal end feet (figures 33 and 34), which make the synaptic endings with the motorneurons of the spinal cord.

The mitochondria clearly exemplify formed complex aggregates, each determining reactions that go on in its neighbourhood. Their mode of formation is unknown, but it may be that they originate at the nucleus (see p. 8), or at the cell surface (p. 17), and are transmitted through the cytoplasm. They are certainly most important in controlling the metabolism of each part and in determining in what reactions a molecule entering that region will become engaged. During the period of active synthesis that occurs in a nerve cell body after section of the axon the number of mitochondria is increased [17].

NEUROFIBRILS

Histological techniques often show the presence of sharply defined fibres within the axon. Fibrils have been seen in living nerve cells in tissue culture, but nevertheless it is probable that they do not usually occur as large discrete entities in normal conditions. The material of cell body, axon, or dendrites may show signs of longitudinal orientation (figure 35). If a giant nerve fibre of a squid or cuttlefish is examined alive in sea water very faint signs of longitudinal striation are seen. If the fibre is then damaged by puncture the striations become much more definite. It seems likely, therefore, that the neuronal material contains elongated particles, which readily fall together to make more definite fibrillae. Fine threads 6–10 mμ in diameter and of indefinite length have been seen by electron microscopy by various workers [31, 27]. Such appearances are indications of the presence of molecules able to form long particles. There is little that can be said at present about their significance, but it seems possible that they constitute a framework or cytoskeleton for the long nerve fibres. If this is so they would not be classed as agents of the intracellular communication system in the sense of carrying signals that initiate specific types of activity, as do the granules previously considered. Yet they may form an essential part of the communication system if the long molecules assist the transport of the signalling particles either by directing the flow or by actively furthering it.

THE NERVE-CELL SURFACE

The action potentials that are the characteristic signals with which the nerve cell operates are set up and propagated by its surface, and the properties of the outer boundary of the cell are therefore of special importance. The membrane is so thin that almost nothing was known of its appearance before the advent of the electron microscope. With the latter it appears as a continuous double membrane of the order of 10 mμ thick over the whole surface of the cell body and dendrites.

The conditions at the axon surface are complicated by the presence of the covering layers of myelin. Axons seldom or never run free, but are covered by the protoplasm of the Schwann cells. The membranes between the protoplasm of the Schwann cell and the axoplasm are elaborated to make the lipoprotein lamellae that provide an insulating surface to the fibre. In the fully medullated nerve fibres of vertebrates the myelin layer, 2 μ or more in thickness, covers the axon except at the nodes of Ranvier, which are separated by distances of a millimetre or more (figure 37). The only part of the axon that is in immediate interchange with the surroundings is the minute region at the node. The current generated at one node thus passes to and excites the next, and the velocity of propagation is thereby increased by the sheath. If a medullated fibre is stained with methylene blue the dye enters only at the node, the myelin preventing access to the rest of the fibre (figures 38 and 39).

In smaller vertebrate nerve fibres, and in those of most invertebrates, there are no nodes. Nevertheless a sheath with several layers is usually present. B. B. Geren and F. O. Schmitt [16] have recently shown that the protoplasm of the Schwann cells around lobster nerve fibres contains several membranous layers. The innermost of these is in direct contact with the surface of the axon, and, indeed, constitutes the outer membrane of the latter (figure 2). This locality is of particular interest because it is here that the interchanges take place by which the nerve fibre is charged and discharged, potassium ions being pumped inwards for charging and sodium outwards [19]. It is therefore of special significance that numerous mitochondria occur in the outer region of the axoplasm, beneath the membrane. Moreover, Schmitt and Geren observed that the innermost layer of the Schwann cell is folded in a manner that suggests that vesicles may become nipped off to form the mitochondria that are especially numerous in the outer layers of the axon (figure 2). If this is true we have here an exceptionally clear example of an interchange that takes place in a quantal manner, by the transfer of quite highly organized units.

At the motor end plate, where the nerve fibre stimulates a muscle, there is an elaborate specialized portion of the neuron, which cannot be here described in detail. Numerous mitochondria are again involved, and the region is one of great metabolic activity. The arrival of action potentials along the nerve fibre serves to trigger off the release at the end plate of sufficient acetyl choline to fire the muscle fibre. Once again quantal processes are involved. P. Fatt and B. Katz [15] have shown that unit quantities of acetyl choline are continually released at the end plate, even at rest. The arrival of the nerve impulse serves to increase the rate of release of the quanta above a threshold level. It is not yet known whether these quantal units are determined by the separation of visible formed bodies from the nerve ending to the muscle. The fact that there are aggregations of bodies at the end plate suggests that this may be so [30]. In any case we see once again evidence that the stability of a part of the living system is assured by the operation of release of units composed of relatively complicated molecular aggregates.

SYNAPTIC GRANULES

There is some evidence that the stimulation of one neuron by another is also accomplished by the release of formed units of material. Granules stainable with acid fuchsin have been known for some time to occur at the synapses of giant cells [4, 43]. In the squid these granules can be seen in the presynaptic endings (figure 15), between the two surfaces (figure 14), and within the postsynaptic neuron (figure 35). There is no certainty that the granules are composed of the same material in all these situations; but they all stain alike, and no other fully comparable material is found elsewhere in the neighbourhood. There is therefore some reason to suppose that in this situation, too, signals are transmitted by the release of standard unit particles.

At the synapses in the spinal cord of mammals the presynaptic fibres are filled with conspicuously large granules (figures 2, 33, and 34). These may be mitochondria or perhaps some more specialized material. Clear evidence of the transfer of particles to the postsynaptic cell is as yet wanting in this case, but some suggestive signs of it have been reported [14].

In a few instances nerve fibres seem to function mainly by the transport of chemical signals along their whole length. Such granules of neurosecretion are found in the fibres that innervate the pituitary body of vertebrates and some glands in invertebrates [21]. Presumably this form of signalling is more effective than the conduction of nerve impulses for the continuous maintenance of a steady level of secretion by a gland. Its interest in the present context is that the stimulating product is transmitted in the form of discrete granules.

CONCLUSION

There is much reason to think that part, at least, of the cellular organization can be described by treating it as a two-way communication system. Events at the cell surface determine changes immediately within the cell membrane. These set in operation other changes proceeding inwards, which ultimately influence the operations of the nucleus. This, in turn, modifies its actions, sending out signals that appropriately alter the reactions in the cytoplasm.

The presence of various types of formed particle in the cell is entirely in accordance with the hypothesis that some form of signalling system is involved—indeed, were the particles not known, their presence could be inferred from the fact that distant parts of the cell maintain a stable pattern of organization under the influence of the nucleus. It is not a question of whether cells are communication systems, since the elementary facts show that they are: the problem is to discover how the information is transmitted. Something must be sent from the cell body down the nerve fibre, for the latter ceases to maintain its steady state if it is cut off. Conversely, something must be transmitted towards the nucleus, for after severence of the axon it proceeds to increased protein synthesis.

It is likely that many of these effects depend upon a transmission system composed of specific preselected control particles, the mitochondria, lipochondria, microsomes, and endoplasmic vesicles.

These particles are certainly not distributed uniformly through the nerve cell. No figures are available for their frequencies in the different parts. If such figures could be obtained, especially from cells in different conditions, they might throw light on the problems of where these bodies are formed and what determines their number in any region. It is not clear whether there is any relationship between any of these types of particle and the granules that are found at synaptic surfaces, but there is enough evidence to suggest that not only these synaptic granules but all the particles are units by which the cell maintains and transmits a stable pattern. It has often been suggested that the cytoplasmic particles are self-reproducing, especially the mitochondria. There is at present little evidence for this, although until we know how they are formed it remains a possibility. The presence of heritable determinants in the cytoplasm is well established (plasmagenes). There is some evidence that some cytoplasmic particles are formed at or near the nuclear surface. It may be that the nucleus provides the signals that ensure maintenance of a steady state by liberating these bodies into the cytoplasm. These instructions must control the metabolism of parts of the cell that are several feet away in the case of a long nerve fibre. It would not be surprising, therefore, to find that they are carried in the form of discrete aggregate particles, which will transmit the instruction more accurately than will a continuous flow of molecules.

It is impossible at present to say more about how these particles arise or how their composition is regulated, as it must be if each is to function as a signal, producing a definite effect in some distant place. We need more information about their site of formation and transport in the cell before the comparison with a communication system can be further developed.

There is enough evidence available to suggest that cellular organization can be described largely in terms of the various specific collections or packets of molecules, which are the means by which the past history of the race, transmitted by the genes, controls daily metabolism.

The electron micrographs of figures 1(*a*), 2(4), 40, and 41 were taken by R. G. W. Wyckoff, to whom the author is greatly indebted. His thanks are also due to Mr J. Armstrong for the colour photography and to Miss E. R. Turlington for the drawing of figures 2 and 41.

REFERENCES

[1] Aitken, J. T., Sharman, M., and Young, J. Z. *J. Anat., Lond.*, **81**, 1, 1947.
[2] Arvanitaki, A. and Chalozonitis, N. *Arch. Sci. physiol.*, **3**, 27, 1949.
[3] Baker, J. R. *Quart. J. micr. Sci.*, **85**, 1, 1945.
[4] Bodian, D. *J. comp. Neurol.*, **68**, 117, 1937.
[5] Borysko, E. and Bang, F. B. *J. appl. Phys.*, **23**, 163, 1952.
[6] Cain, A. J. *Quart. J. micr. Sci.*, **89**, 421, 1948.
[7] Caspersson, T. 'Cell growth and cell function', W. W. Norton and Company Inc., New York. 1950.
[8] Casselman, W. G. B. *J.R. micr. Soc.*, **74**, 209, 1954.
[9] Causey, G. and Hoffman, E. *Proc. roy. Soc.* In press.
[10] Claude, A. *Biol. Symp.*, **10**, 111, 1943.
[11] Claude, A. and Fullam, E. F. *J. exp. Med.*, **81**, 51, 1945.
[12] Darlington, C. D. *Symp. Soc. exp. Biol.*, **1**, 252, 1947.
[13] Davidson, J. N. 'The biochemistry of the nucleic acids'. Methuen and Company Limited, London. 1953.
[14] de Robertis, E. *J. Histochem. Cytochem.*, **2**, 341, 1954.
[15] Fatt, P. and Katz, B. *J. Physiol.*, **117**, 109, 1952.
[16] Geren, B. B. and Schmitt, F. O. *Proc. nat. Acad. Sci., Wash.*, **40**, 863, 1954.
[17] Hartmann, J. F. *Anat. Rec.*, **100**, 49, 1948.
[18] *Idem. Ibid.*, **118**, 19, 1954.
[19] Hodgkin, A. L. *Biol. Rev.*, **26**, 339, 1951.
[20] Hyden, H. *Acta physiol. scand.*, **6**, 5, 1943.
[21] Knowles, F. G. W., *Endeavour*, **14**, 95, 1955.
[22] Krebs, H. A., Bartley, W., and Davies, R. E. *Proc. roy. Soc. B*, **142**, 187, 1954.
[23] Legendre, R. *Arch. Anat. micr.*, **10**, 287, 1908.
[24] Mandelbrot, B. *Word*, **10**, 1, 1954.
[25] Moore, K. L. and Barr, M. L. *J. comp. Neurol.*, **98**, 213, 1953.
[26] Palade, G. E. *J. Histochem. Cytochem.*, **1**, 188, 1953.
[27] Palay, S. L. and Palade, G. E. *J. Biophys. biochem. Cytol.*, **1**, 69, 1955.
[28] Parat, M. *Arch. Anat. micr.*, **24**, 73, 1928.
[29] Peters, R. A. 'Perspectives in Biochemistry'. Ed. J. Needham and D. A. Green, Cambridge. 1937.
[30] Robertson, D. In press, 1955.
[31] Schmitt, F. O. and Geren, B. B. *J. exp. Med.*, **91**, 499, 1950.
[32] Schneider, W. C. and Hogeboom, C. H. *Cancer Res.*, **11**, 1, 1951.
[33] Schneider, W. C. *J. Histochem. Cytochem.*, **1**, 212, 1953.
[34] Shannon, C. E. *Bell Syst. tech. J.*, **27**, 379, 1948.
[35] Spector, W. G. *Proc. roy. Soc. B*, **141**, 268, 1953.
[36] Thomas, O. L. *Quart. J. micr. Sci.*, **88**, 445, 1947.
[37] Weiss, P. and Taylor, A. C. *J. exp. Zool.*, **95**, 233, 1944.
[38] Worley, L. G. and Worley, E. K. *J. Morph.*, **73**, 365, 1943.
[39] Worley, L. G. *Ann. N.Y. Acad. Sci.*, **47**, 1, 1946.
[40] Young, J. Z. *Quart. J. micr. Sci.*, **75**, 2, 1932.
[41] *Idem.* 'Essays on Growth and Form'. Ed. W. E. Le Gros Clark and P. B. Medawar. Clarendon Press, Oxford. 1945.
[42] *Idem. Quart. J. micr. Sci.*, **94**, 399, 1953.
[43] *Idem. Phil. Trans. B*, **229**, 465, 1939.

Thoughts on optical activity

H. M. POWELL

It is a tribute to the genius of Pasteur that his main conclusions on optical activity remain unchallenged and his three methods of resolving optically active substances found no significant addition for nearly a century. In recent years, however, new methods of resolution have been used. New classes of optically active materials arise when a surrounding molecular structure will include a molecule more readily as one enantiomorphous form than as the other. The existence of other kinds of optically active substances can also be foreseen.

That substances of certain chemical constitutions can be obtained in two forms differing only in that their molecules are related as non-superposable mirror images of each other was discovered by Pasteur [1] many years before precise structural formulae had been assigned to simple organic compounds. The idea that molecular shapes may have left and right mirror-image forms is perhaps very much older, since Lucretius wrote [2]:

fac enim minimis e partibus esse
corpora prima tribus, vel paulo pluribus auge;
nempe ubi eas partis unius corporis omnis,
summa atque ima locans, transmutans dextera laevis,
omnimodis expertus eris, quam quisque det ordo
formai speciem totius corporis eius . . .[1]

In other passages the poet describes corpuscles that are solid enough, and in a later book talks of turning a wet plaster cast inside out in order to form a mirror-image of the familiar kind, with the right eye appearing on the left. Although in the lines quoted Lucretius does not mention back and front, he also does not state the shape of the three least parts, and any suspicion that this corpuscle is two-dimensional, and thus superposable on its mirror image, may be disregarded.

Some natural substances give solutions such that when plane-polarized light is passed through them the plane in which the transverse light vibrations may be imagined to take place is rotated through an angle about an axis coincident with the direction of the light. The extent of the rotation is proportional to the amount of material that the light has passed through, and the effect, thus shown to be unconnected with any action at the surface, must be brought about by the molecules. Crystals of plant-formed tartaric acid and its salts show hemihedral faces and are not superposable on their mirror-images. Racemic acid, indistinguishable in composition and in some properties from tartaric acid, does not rotate the plane of polarization, has a different crystalline form, and does not show hemihedral faces. Its salts also, as ordinarily prepared, show no hemihedrism, with the exception of sodium ammonium racemate, which Pasteur found to give two sets of hemihedral crystals. One of the latter was identical with the corresponding salt made from natural tartaric acid, and the other was its mirror-image form, previously unknown. The crystals may be separated by hand, and from the second sort there may be obtained a variety of tartaric acid differing from the ordinary one virtually only in that its solution rotates the plane of polarization to the same extent but in the opposite sense.

Many substances are now known to exist similarly in *dextro* and *laevo* forms, and in all cases the molecule, for one reason or another, has a three-dimensional form which is not superposable on its mirror image. It may have no symmetry, but, like a propeller, it may have one or more axes of rotational symmetry: on rotation about such an axis through an angle of $360°/n$ (n being a small integer) the molecule appears the same as in the starting position. It cannot have any symmetry which implies a mirror-image operation. Such a body is conveniently described as dissymmetric.

Almost all laboratory reactions for making these substances yield equal amounts of *dextro* and *laevo* molecules and the product gives an optically inactive solution, since molecules which bring about rotation to the right are counteracted by the equal number which cause rotation to the left. This does not apply when one of the starting materials is itself used in an optically active form, but equal amounts of both enantiomorphs are produced by nearly all methods of forming dissymmetric molecules from others which are optically inactive.

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[1] 'For suppose that corpuscles consist of three least parts, or add a few more. When, by attaching these at top and bottom and transposing right and left, you have tried every possible shape that methodical arrangement of the parts can confer on the form of the body as a whole . . .'

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No special influence is required to form a dissymmetric molecule, but the space relationship of the reacting molecules at the appropriate times results in one or other mirror-image form. If the reaction is not affected by a dissymmetric influence, either from within or without the molecule, there is an equal chance that the *dextro* or *laevo* form will result. Since on a laboratory scale the number of molecules involved is immense, the product will differ from an equal mixture only to a minute, optically undetectable, extent.

Spontaneous resolution of such racemic mixtures on crystallization has been observed comparatively rarely. It is known of some substances, and thought to be true of many others, that their crystalline structures contain equal numbers of *dextro* and *laevo* molecules in the same way as most of the salts of racemic acid originally examined.

To separate a *dl* mixture Pasteur proposed to apply a dissymmetric influence which would act differently on the two forms. He achieved this [3] in one way by acting on a mixture with another substance which was already available in either a *dextro* or *laevo* form. A *dl* acid on reaction with a *d'* base may give the products *dd'* and *ld'*. These are not mirror-image forms, and they differ in solubility and other properties like any other pair of non-enantiomorphous substances. Consequently they may be separated by ordinary methods.

Another of Pasteur's methods [4] of obtaining optically active material from a racemic mixture involved the use of living organisms. When ammonium racemate was subjected to fermentation the yeast caused the salt of one hand only to ferment.

A number of other methods practised or suggested involve the application of a dissymmetric influence. For example, some media show unequal absorption of circularly polarized light according as it is left- or right-handed, and in suitable mixtures this might lead to selective destruction of one enantiomorph [5]. Photochemical reaction under the influence of left- or right-circularly polarized light may favour the production of one form [6]. Another method uses adsorption of the substance on surfaces which might be expected to behave differently towards right- and left-handed molecules, e.g. the surfaces of crystals, like quartz or cane sugar, which may be obtained in forms not superposable on their mirror-images [7]. A recent exploitation of supersaturation phenomena resulted in the resolution of large amounts of material such as racemic threonine [8]. Only a small quantity of one optically active form is required to start a series of operations which give alternately crops of the *dextro* or *laevo* forms. Large quantities of the two forms may be separated, but it is the dissymmetric influence of the original active material that makes the procedure possible.

Pasteur repeatedly emphasized a distinction between the chemistry of living matter and that of laboratory reagents. Briefly, he said that, in contrast to artificial laboratory products, the essential products of life are dissymmetric in such a way that they cannot be superposed on their mirror images. He lists cellulose, starches, gums, sugars, tartaric and malic acids, morphine, strychnine, turpentine, albumen, and gelatine, among others, as dissymmetric. Very vigorously he refuted claims for exceptions based on resolution by living organisms, pointing to the dissymmetry introduced by the organism itself.

Pasteur did not suggest that dissymmetric substances cannot be synthesized; on the contrary, he went to great efforts to achieve it through the application of dissymmetric forces. This he attempted by a variety of methods, some of which he later considered crude. He looked upon the universe as dissymmetric, saying that if the solar system, with the proper movements of the heavenly bodies, were placed before a mirror its image would not be superposable on the reality. Similarly the Earth, with its magnetic poles, provides an object not superposable on its mirror-image. In order to imitate nature, he said, it is necessary to have recourse to dissymmetric forces, as in the action of solenoids, of magnetism, of dissymmetric movements of light, and the action of substances which themselves are dissymmetric. At Strasbourg he had powerful magnets constructed by Ruhmkorff, and at Lille he made use of turning movements effected by clockwork. In view of the opposite polarities associated with magnetism he felt justified in posing this question concerning the formation of hydrocarbons from the carbon in a steel magnet [9]: '*l'aimant, pénétré de ce je ne sais quoi qui le fait aimant et qui est, j'imagine à image non-superposable, ne donnerait-il pas, au moment de la mystérieuse combinaison de son carbone avec l'hydrogène, des molécules dissymétriques? J'irais plus loin; je voudrais comparer les carbures d'hydrogène formés simultanément et séparément par l'attaque des deux pôles d'un aimant.*' He wondered what would happen if albumen, cellulose, and other constituents of microbes could be replaced by their mirror-image forms.

Some products of life are not dissymmetric and many inorganic compounds showing dissymmetry have been synthesized, but since the time of

Pasteur there has been speculation as to how nature carries out much of living chemistry in a dissymmetric way. W. H. Mills [10] has related it to a process of growth. A minute difference in the proportion of *dextro* and *laevo* molecules, such as could occur in a small unit of a living system, would ultimately lead to dissymmetric chemical changes more efficient than the corresponding set of reactions with racemic materials. E. Havinga [11], who nevertheless has a possible answer, remarks that the question as to how the first dissymmetric material can have been brought into being in living organisms is in itself not overwhelmingly urgent. This problem may be combined with the great mystery of the first life, and one may just as well suppose that the first life was dissymmetric as that the first living matter came into being and that it later made use of optically active material.

However this may be, there is a special interest in processes which result in the production of optically active materials without deliberate introduction of any other substance in a resolved form.

When W. J. Pope and S. J. Peachey [12] used *d*-camphor-sulphonic acid to resolve methylethyl-*n*-propyl tin they obtained the whole of the tin complex salt in the *d* form without the *l* form accumulating in the mother liquors. This happened because in solution there was rapid racemization of the complex which was removed in one form only into the crystal, where it does not racemize. Although this experiment required the use of the optically active camphor derivative it shows how rapid racemization may be exploited to achieve a form of asymmetric synthesis.

The nucleation of a saturated solution of a racemate by a crystal containing an excess of one optically active form has been observed very often. For example, L. Anderson and D. W. Hill [13] found that the first material deposited from a solution of racemic atropine sulphate usually had the *l* form when the crystallization was carried out in a laboratory where the *l* form had been racemized. Although in such circumstances the laboratory atmosphere would supply seeds, it seems that in some experiments of this kind crystallization is induced by material that is not optically active. E. Darmois [14], in 1953, published details of some earlier experiments in which an optically active alkaloid could be obtained from its racemic hydrochloride by precipitation with pyridine. This is attributed to preferential nucleation, but no optically resolved materials are used to start it. R. C. Ferreira [15] achieved a slight optical separation of narcotine in this way.

Havinga carried out an experiment with optically inactive material. Methylethylallylphenylammonium iodide crystallizes with one molecule of chloroform as a conglomerate of *dextro* and *laevo* crystals. At room temperature a solution of the optically active form racemizes rather slowly, showing a considerable rotation at the end of five weeks; by very slow cooling of a racemic solution a crystal, or crop of crystals, of one hand only was obtained.

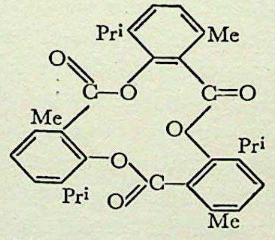
Recently, resolutions without the use of optically active materials have been accomplished with the aid of crystalline molecular compounds.

In many crystalline molecular compounds molecules of two different kinds together form the lattice; the complexes here considered have no chemical bonding between the components. In a special class of these compounds one component forms a structure enclosing a set of spaces in which the molecules of a second sort are contained. Whether a particular molecule can be so enclosed depends on its shape and size, since it must, for enclosure, be able to fit into the available cavity. The formation of such compounds may be applied to separate substances which are chemically and physically similar but have different molecular shapes; as a special case of this, *dextro* and *laevo* molecules may be separated. If the surrounding structure consists of an arrangement of atoms which is not superposable on its mirror-image then the cavities also will be different from their mirror-images, and thus may be able to include one form of some other molecule although they reject its enantiomorph. Dissymmetry of an enclosing structure may arise when the cage-forming material is optically active, optically inactive, or racemic.

An example of the enclosing structure being itself optically active is afforded by the cyclodextrin inclusion compounds [16] in which molecules are enveloped in the large ring system of the cyclodextrin molecule derived from dextrose. A partial optical resolution of racemic substances such as mandelic ester has been made by means of these compounds. It depends on inclusion, but the reagent used is in this case optically active.

Molecules of a substance which is optically inactive in solution may in the crystal build up enantiomorphous structures, for example by arrangements in left- or right-handed spirals. Either form could crystallize and both could appear together, but preferential nucleation may cause a predominance of one form in the product. Examples are provided by the urea adducts with aliphatic molecules. The spaces in which the molecules are enclosed are, to a first approximation, a set of uniform cylinders arranged as the spaces of a honeycomb. The walls of the cylinders are in reality made up of a hexagonal spiral of urea molecules. Although the difference from a uniform cylinder does not appear to be very great, the adducts can be used to separate secondary octyl chloride and other substances into their enantiomorphous forms [17]. The extent of resolution is not clear, though it is reported that the process must be repeated a number of times.

The cage structure may be composed of the optically active molecules of a substance which is used as a racemate. Such a substance could form a non-enantiomorphous cage structure composed of equal numbers of *d* and *l* molecules; in this case the cavities would not be dissymmetric or they would, like the enclosing molecules, occur in mirror-image pairs. Such a structure would not be expected to be selective for the *d* or *l* form of an enclosed component. Alternatively, on formation of the crystalline molecular compound there may be separation into a conglomerate of *d* and *l* crystals. If one crystal of the product contains only the *d* form of the enclosing molecules this is necessarily enantiomorphous. Its cavities will be the non-superposable mirror-images of those in the *l* crystals which constitute the other kind in the conglomerate. Tri-*o*-thymotide (represented below) and its adducts illustrate this case [18].



Tri-*o*-thymotide is itself optically active, and it crystallizes alone as a racemate. Although it has been resolved, it can in effect be used only as a mixture of *d* and *l* forms, since it racemizes very rapidly in solution, having a half-life period of a few minutes at room temperature. From many solutions it is obtained in the form of crystalline adducts with solvent. These have a variety of crystalline structures. Some are racemates, but many are conglomerates of *d* and *l* crystals. These crystals are not distinguishable by any enantiomorphous face-development, but they can be shown by X-ray diffraction experiments to belong to enantiomorphous space-groups. In any one crystal, tri-*o*-thymotide molecules of one hand only are present. Racemization does not occur in the crystal at ordinary temperatures. In the crystalline adduct the tri-*o*-thymotide molecules are arranged in a spiral so that one of the enantiomorphous crystals has molecules of one hand in a right-handed spiral and its mirror-image has the opposite hand of molecules arranged in a left-handed spiral. Optically inactive molecules such as benzene or *n*-hexane may be enclosed in the cavities, and by reason of their symmetry will fit equally well into either of the structures.

One form of optical resolution is that of the tri-*o*-thymotide itself when the adduct with benzene is formed. By slow cooling the whole yield may be obtained as one or more large crystals. Any one of these necessarily contains only one hand of the tri-*o*-thymotide molecules and is thus resolved by a process which is a simpler form of Pasteur's first method. In any case, once a crystal nucleus forms it tends to produce more nuclei of its own kind, and either spontaneously, or with the help of deliberate seeding, a crop of predominantly one kind of crystals may be obtained without the need to grow large single crystals. Since the half-life period for racemization is short compared to the time for growing the crystals, all the tri-*o*-thymotide removed in some experiments is of one hand. The only thing added to the originally racemic tri-*o*-thymotide is the optically inactive benzene.

The enantiomorphous character of the cavities in suitable molecular compounds may also be used to separate racemic mixtures. One series of tri-*o*-thymotide molecular compounds, formed only with molecules which do not exceed a certain critical size, has closed cavities. The dimensions of the dissymmetric secondary butyl bromide molecule permit its enclosure. The product of the slow cooling of a solution of tri-*o*-thymotide in racemic secondary butyl bromide in general contains unequal amounts of left and right crystals. Either with or without seeding it can be obtained predominantly in one form, and the fraction of the crop having the *d* or *l* form may be estimated by comparison of the optical activity with that of completely resolved tri-*o*-thymotide. This is possible because the initial rotation of the tri-*o*-thymotide solution is very much greater than that of the enclosed material. The secondary butyl bromide recovered is found to be optically active. The optical resolution has been brought about without the use of an optically active material in resolved form. The extent of the resolution is found to be the same as that of the unequal conglomerate of the tri-*o*-thymotide that encloses it.

This is what would be expected if each cavity entirely excluded one form of the secondary butyl bromide. Such behaviour is to be expected when the empty space is, like the space in a boot, not superposable on its mirror-image and the enclosed molecule, like the normal foot, fills most of the space. A sufficiently small left foot will go into a right boot, and analogous behaviour may be expected in some inclusion compounds.

For ordinary dissymmetric substances the crystalline forms known are racemates, *d* and *l* forms in equal or unequal conglomerates, and a variety of mixed or complex crystals, pseudo-racemates and twinned forms. The examples of optically active molecular compounds, which do not exhaust the possible combinations of active and inactive constituents, suggest that there may be other types yet to be discovered.

A crystalline molecular compound formed by the building of a complex lattice, but not dependent on inclusion of one component, could have both partners racemic, one racemic and one optically active, or both optically active. If they are stoicheiometric, the rotations of the various forms will be interrelated. A special case would be that of a structure containing *d* and *l* forms of the same substance in fixed but unequal amounts. Crystal structures are known in which two or more geometrically different positions in the unit cell are occupied by molecules of the same constitution to form a complex pattern. There could be unequal, but fixed, numbers in different positions, or equal numbers in several different positions. Some of these forms could be optically active because the overall composition is of the form $d_n l_m$, *n* and *m* being integers. If the *d* and *l* forms are stable, the rotation of such a substance would be constant. A *dl* mixture might in some circumstances spontaneously resolve into $d_n l_m$ and $l_n d_m$ crystalline forms that might be mistaken for *d* and *l* because they have constant equal, but opposite, rotations.

As has been seen, the enclosed and enclosing components of inclusion compounds similarly may have various optical forms. In the limiting case, when the cavities are all filled and are strictly selective for one enantiomer, there will be a definite rotation related to the nature and proportion of the components. The effects of empty spaces and diminished selectivity can be easily worked out.

Special effects may be expected in the case where the cage is closed but is large enough to hold more than one molecule of suitable size. Structures of this kind have been discovered. One case only will be considered here [19]. The cage is centrosymmetric. If it forms from solution in a racemic solvent we might expect to get some cavities with a *d* and some with an *l* enclosed molecule or, with sufficiently small molecules, cavities with one *d* and one *l* each. Provided one cavity and its contents has a negligible influence on another, these forms will be optically inactive. A curious effect can thus be foreseen. Suppose the centrosymmetric cage forms from a *d* solvent. The dimensions are such that one *d* and one *l* will fit, but once the cavity contains a *d* molecule the remaining space is the wrong mirror-image form for a second *d* molecule, which might be as rigorously excluded as the wrong form of secondary butyl bromide in the tri-*o*-thymotide adducts. The molecular compound formed from *d* or *l* solvent should therefore include only half as much material as that obtained with racemic solvent. Partly resolved mixtures should give molecular compounds of intermediate compositions, and thus the extent of an optical resolution of a previously unresolved substance might be estimated.

REFERENCES

[1] PASTEUR, L. *C.R. Acad. Sci., Paris*, **26**, 535, 1848.
[2] LUCRETIUS. 'De Rerum Natura', ii, 485.
[3] PASTEUR, L. *C.R. Acad. Sci., Paris*, **37**, 166, 1853.
[4] 'Leçons de Chimie professées en 1860'. Hachette, Paris. 1861.
[5] COTTON, A. *C.R. Acad. Sci., Paris*, **120**, 989, 1895; KUHN, W. and KNOPF, E. *Z. phys. chem.* B., **7**, 292, 1930.
[6] KARAGUNIS, G. and DRIKOS, G. *Nature, Lond.*, **132**, 354, 1933.
[7] TSUCHIDA, R., KOBAYASHI, M., and NAKAMURA, A. *J. chem. Soc., Japan*, **56**, 1339, 1935.
[8] VELLUZ, L., AMIARD, G., and JOLY, R. *Bull. Soc. chim. Fr. Docum.*, **20**, 342, 1953.
[9] PASTEUR, L. *C.R. Acad. Sci., Paris*, **58**, 1515, 1874.
[10] MILLS, W. H. *Rep. Brit. Ass.*, 37, 1932.
[11] HAVINGA, E. *Chem. Weekbl.*, **38**, No. 46, 1941.
[12] POPE, W. J. and PEACHEY, S. J. *Proc. chem. Soc. Lond.*, **12**, 42, 116, 1900.
[13] ANDERSON, L. and HILL, D. W. *J. chem. Soc.*, 993, 1928.
[14] DARMOIS, E. *C.R. Acad. Sci., Paris*, **237**, 124, 1953.
[15] FERREIRA, R. C. *Nature, Lond.*, **171**, 155, 1952.
[16] CRAMER, F. *Angew. Chem.*, **64**, 136, 1952.
[17] SCHLENK, W. *Experientia*, **8**, 337, 1952.
[18] POWELL, H. M. *Nature, Lond.*, **170**, 155, 1952.
[19] BAKER, W. and MCOMIE, J. F. W. *Chem. and Ind. (Rev.)*, 256, 1955; POWELL, H. M. and WETTERS, B. D. P. *Ibid.*, 256, 1955.

Muslim mechanics and mechanical appliances

H. J. J. WINTER

The story of the presentation of a water-clock to the emperor Charlemagne by the caliph Hārūn al-Rashīd is well known, and the Arabs and Persians excelled in the making of such contrivances, but an understanding of the state of the science of mechanics as a whole in medieval Islām is difficult to attain. It comprises not only the legacy of Greek thought and experiment, with practical applications in evidence from the palace of Alhambra to the mosques of Samarkand, but a few remarkable advances springing from its own genius.

Of the Greek authors whose writings on mechanics were rendered into Syriac and Arabic during the period of translation and assimilation (roughly A.D. 750–900), Euclid, Archimedes, Apollonius, Hero, and Philo were the most revered. The 'Mechanics' of Hero of Alexandria (translated about 860 by the Nestorian Christian, Qusta bin Lūqā of Baalbek, for the caliph al-Musta'īn), and the 'Pneumatics' of Philo of Byzantium, the translator of which is unknown, inspired both new writings and a wide range of practical devices. Thus the Banū Mūsā, the three sons of Mūsā ibn Shākir (who was himself a friend of the caliph Al-Ma'mūn), were the authors of the 'Book of Artifices' (*Kitab al-ḥiyal*) [1], which describes one hundred pieces of technical equipment. The greater proportion were novelties, following Philo, and can be classed as mechanical toys, but some of the inventions developed from the ideas of Hero had great practical significance. In medieval Islām during the ensuing period (*c.* 900–1100)—when science was widely accepted and new advances were being made—applications were made of all the simple machines such as the lever, wheel and axle, pulley, inclined plane, toothed wheel, endless screw, siphon, and pump, together with the water-wheel and windmill.

The so-called Golden Age of Islamic science owed its importance largely to the Persian contribution. The language of Iran had assumed a new significance, and a creative spirit was being born in her scholars as the tenth century dawned. Among those who wrote eloquently in this language rich in imagery were Ibn Sīnā (980–1037), Abū Raiḥān Al-Bīrūnī (973–1048), and 'Umar Khayyām (d. *c.* 1123), though their scientific works are largely in Arabic, a medium better suited to terse and deductive argument. To the Arabic language we also owe a great debt for its preservation of the classics of Greek science.

In the realm of mechanics Ibn Sīnā is noted mainly for his theoretical postulates, our subject representing to him the lowest level of a great scheme of speculative philosophy. These postulates are highly ingenious and sometimes correct. He wrote in *Al-kitāb al-najāt* that 'no body begins to move or comes to rest of itself', a clear statement of the principle of inertia; that 'time cannot be imagined without movement'; and that force is measurable only in terms of its effects. Again, in any simple machine, 'what is gained in power is lost in speed'. Ibn Sīnā also regarded the problems of statics as fundamentally those of dynamics, whence he proceeded to explain the impact of bodies from the standpoint of dynamic forces acting from within the bodies. But in one respect his theory of mechanics proved inadequate, for he thought only in terms of uniform velocity, as did Aristotle and Al-Kindī before him. By regarding time as continuous, and as being interpreted in terms of the 'quantity of circular motion' of the celestial sphere, he was diverted by these basic assumptions from any consideration of either acceleration or centrifugal force. The significance of Newtonian mechanics, and the reason why it enabled the foundations of modern science to be established, rest precisely in these two latter phenomena, whereby the false postulate that a prime mover or force is required to maintain a body at a uniform velocity in the line of action of the force was overthrown. Despite such weakness in his postulates, Ibn Sīnā was able to work successfully in the immediate practical field, and is credited with a device similar to the vernier.

Al-Bīrūnī, a man of deep erudition and an experienced traveller, is noted especially for his accurate determination of the specific gravities of eighteen precious stones and minerals. These

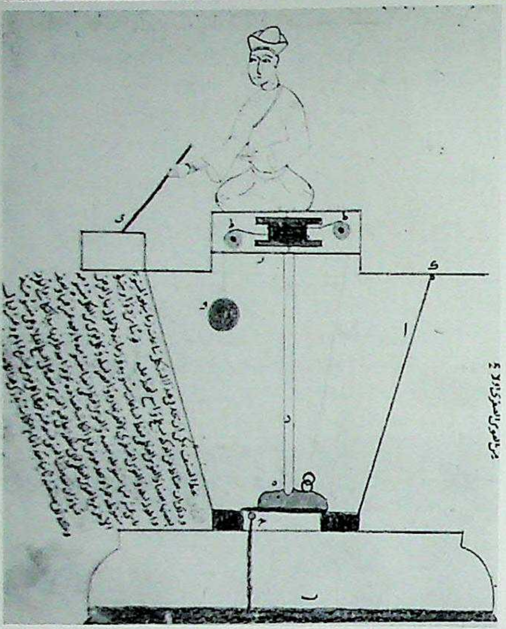


FIGURE 1 – *A water (beaker) clock in Al-Jazarī's treatise.* (*From MS. Graves 27, Bodleian Library, by courtesy of the Librarian.*)

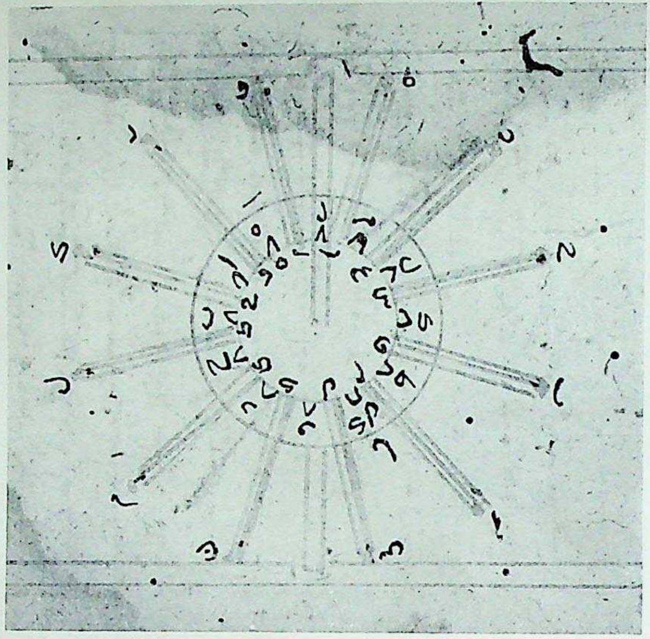


FIGURE 2 – *Diagram of a Persian water-wheel.* (*From Arabic MS. 351, Rylands Library, Manchester, by courtesy of the Librarian.*)

results he studied and tabulated systematically, and it is significant to note that no such tables appeared in Western Europe until the seventeenth and eighteenth centuries, when Boyle's value for the specific gravity of mercury, for instance, was less accurate than that known to the Arabs. Al-Bīrūnī used a 'conical instrument'—a flask-like vessel with a spout projecting from the neck—to determine the volumes of metals by displacement.

'Umar Khayyām, best known as a poet, but perhaps more deserving of recognition as the author of the finest algebraical treatise of the Middle Ages, has his place in the history of the balance, following Archimedes, Menelaus, and Muḥammad ibn Zakarīyā of Ray, and preceding Al-Muzaffar ibn Isma'īl al-Isfazārī and Abū'l-Fatḥ 'Abd al-Raḥmān al-Manṣūr al-Khāzinī. Since the technique of the balance became a special science in medieval Islām, as, for example, did the study of the rainbow, we shall refer to it when describing the achievements of Al-Khāzinī.

An interesting essay on the vacuum was written by the philosopher Abū Naṣr al-Fārābī [2]. Until recently believed to have been lost, a manuscript of this essay was discovered in Ankara University and is now in the Ismail Sāip Collection (Series I, No. 183 (ii)). Although it refutes the existence of a vacuum it does so only with reference to two particular experiments with flasks containing air and water, and for which experiments the refutation is, in fact, valid. What is most striking in this essay, however, is an analysis of the experimental results based upon the elasticity of the air. Indeed, one of the joys of the historian of science who is able to interpret medieval Oriental manuscripts is that of finding among many pages of tedious matter some angle of approach, or perhaps a discovery, unknown to the Latin West. On the other hand, one learns to receive the views of earlier writers on the history of science with caution. Thus Humboldt attributed to Ibn Yūnus the application of the pendulum to the measurement of time, a statement which the writer has failed so far to substantiate from original manuscripts and which is probably untrue. Though the Arabs had splendid water-clocks, and study of the history of their science is always liable to reveal surprising achievements, as in Al-Khāzinī, a precursor of Galileo seems unlikely.

Of the later Islamic treatises on mechanics two are outstanding, namely *Al-Kitāb fī ma'ar'ifat al-ḥiyal al-handasīya* (The book of the knowledge of ingenious geometrical (mechanical) contrivances) [3] by Abū'l-'Izz Isma'īl ibn ur-Razzaz al-Jazarī Bādī'az-Zamān, and *Al-Kitāb mīzān al-ḥikma* (The book of the balance of wisdom) [4] by Al-Khāzinī of Merv. The former is by far the less original but serves as a summary of the various forms of contemporary apparatus; its author was primarily a craftsman, and had advanced somewhat in technique beyond Hero and Philo, being able to use with advantage the work of his Muslim predecessors. Completed in 1206 for the Urtuqid Sultan Maḥmūd, ruler in Amida—Al-Jazarī had been in the service of the dynasty since 1181–82—the book was held in esteem by three Urtuqid Sulṭāns and later translated into Persian and Turkish. Main interest centres upon elaborate water-clocks for telling the hours and hydraulic apparatus used in the raising of water. A knowledge is shown of the action of paddles, cogwheels, and revolving shafts. In a typical water-clock a copper beaker is initially full, the float being at the surface of the water and the weight at the bottom; as the beaker empties the float sinks and the weight rises, thus rotating a central spindle. The rod held by the figure of a scribe passes over an engraved lid, thereby tracing the passage of the hours (figure 1).

In the year 1860 there appeared in the Journal of the American Oriental Society translations of two remarkable works—the version of the *Sūrya-Siddhānta* of the Hindus, made by Ebenezer Burgess, and the treatise of Al-Khāzinī, just mentioned, first rendered accessible to Western scholars by N. Khanikoff, Russian Consul-General in Tabrīz. This most important occasion has probably been forgotten by most historians of science, and it is refreshing to recall it through the second of these translations. 'The Book of the Balance of Wisdom' is one of the great treatises on mechanics. Though it deals principally, and in great detail, with the practice of accurate weighing and the determinations of specific gravities, it also discusses gravitation, flotation, and geodesy. Written at the request of Abū-l-Ḥārith Sanjar ibn Mālikshāh ibn Alpārslān in 1121–22 'for his high treasury', it paid particular attention to the specific gravity of alloy coinage, including *ad hoc* calibration of the balance arm, and it referred to the Archimedean solution of the problem of Hiero's crown. The comprehensive nature of Muslim study of the balance may be seen from this quotation from 'The Book of the Balance of Wisdom': 'Novelties and elegant contrivances in the way of balances, such as: the balance for weighing dirhams and dīnārs without resort to counterpoises; the balance for levelling the earth to the plane of the horizon; the balance known as "the even balance", which weighs from a grain to a thousand dirhams or dīnārs, by means of three pomegranate-counterpoises; and the hour-balance, which makes known the passing [secular] hours, whether of the night or the day, and their fractions in minutes and seconds, and the exact correspondence therewith of the ascendant star, in degrees and fractions of a degree.' Hour-balances consisted essentially of a long lever, one arm of which carried a vessel of water emptying in twenty-four hours, the other arm a sliding weight acting as a counterpoise and moving over the calibrations on the arm. It was usual to calibrate the right-hand arm by silver enchased at appropriate distances along it, and the divisions were in units corresponding to the particular function of the balance, e.g. units of time, values of specific gravity. The Arabs were thoroughly familiar with the application in surveying and building of the parallelism of a balance beam with the plane of the horizon when the beam is evenly loaded.

A further reference to Al-Khāzinī will serve to indicate the extreme care with which specific gravity determinations were carried out. He says: 'We have made all our comparisons in one single corner of the earth, namely, in Jurjānīyah, [a city] of Khuwārazm, situated where the river of Balkh becomes low, at its outlet upon the little sea of Khuwārazm, the water of which river is well known, of no doubtful quality, and [all our operations have been performed] early in the autumnal season of the year'.[1] Not only was Al-Khāzinī aware of the necessity of removing, as far as possible, the influences of impurity and temperature variation, but he classed the balance with the astrolabe as a precision instrument demanding the greatest care in construction and maintenance, for a good balance detected 1 mithqāl in a total of 1000 mithqāl; and he suggested about 4 bazaar-cubits (2 metres) as the length of the beam, 'because length influences the sensibility of the instrument', and 1 cubit as the length of the pointer. Use of a scale and pointer was probably first suggested by Muḥammad ibn Zakarīya of Ray. By the time of Al-Khāzinī five thin hemispherical scale-pans, made of bronze, were in use with the balance, two being permanent, two additional, and one movable along the right-hand arm, their function being to cover all the various determinations involving weighing in liquids, etc. Commercial applications largely concerned the specific gravities of alloys and gems. Some of Al-Khāzinī's results are shown, in modern terms, in the accompanying table, and without attempting any critical analysis of their accuracy we see at once that they are remarkably close to values now accepted:

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[1] Khanikoff identified this place with the site of Kuna-Urghenj. It appears that by the twelfth century A.D. the Oxus emptied into the Sea of Aral and not into the Caspian.

Gold	19·05 (cast)	Fine pearl	2·60
		Ivory	1·64
Mercury	13·56	Sweet water	1
Brass	8·57	Water (boiling)	0·958
Emerald	2·75	Olive oil	0·920

The areometer of Pappus in an accurate form was also well known to Al-Khāzinī. Consisting of a uniform hollow copper tube, weighted at one end with a hollow cone of tin, and with two ends 'resembling two light drum skins', it floated vertically in liquids, being calibrated in both values of specific gravity and of volumes displaced. An interesting diversion made by Al-Khāzinī was to calculate the weight of the Earth were it to consist solely of gold, for 'truly there will not be accepted as ransom from those who were infidels and died infidels as much gold as would fill the earth; for them are severe pains; they shall have no defender' [Qur'ān, III, 85].

Finally, we may examine Al-Khāzinī's views on gravitation. Although he followed in the tradition of Archimedes, Euclid, Menelaus, Ibn Al-Haitham, and Abū Sahl al-Kūhī, his views were unusually advanced for a medieval scientist, and in spite of the errors which they undoubtedly contain, the insight of their author cannot fail to compel respect. Thus, 'heaviness is the force with which a heavy body is moved towards the centre of the world' and 'a heavy body is one which is moved by an inherent force, constantly, towards the centre of the world' [Lecture I, Chap. I, Sect. 1]. Further, 'That point in any heavy body which coincides with the centre of the world, when the body is at rest at that centre, is called the centre of gravity of that body' [Lecture I, Chap. I, Sect. 4]. The Aristotelian hypothesis on motion, however, died hard: 'Bodies alike in gravity are those which, when they move in a liquid from some single point, move alike—I mean, pass over equal spaces in equal times' [Lecture I, Chap. I, Sect. 4]. Again, 'the weight of any heavy body, of known weight at a particular distance from the centre of the world, varies according to the variation of its distance therefrom; so that, as often as it is removed from the centre, it becomes heavier, and when brought nearer to it, is lighter . . .' [Lecture I, Chap. V, Sect. 3]. Such statements as the last two remind us that we are not yet in the realm of modern science, for in the latter case Al-Khāzinī had in mind the fact that as the atmosphere became rarer, the upthrust exerted by displaced air would be reduced. In fact he assumed that air has weight, although he attempted no measurements.

The Arabs widely exploited natural sources of power, windmills and water-mills (figure 2) being constructed where climate and geography permitted [5]. Thus, according to Mustaufī, '10 leagues to the north of this city (Nishapur) is a mountain from which flows a river which causes several mills to turn with great speed', while Marrākeshī states that 'there are in the city (of Marrakesh) and even under the surrounding walls, some three hundred water-mills'. In Afghanistan, where the winds blew without cessation, carrying great clouds of sand, nature's tremendous forces were recognized and harnessed. Al-Mas'ūdī (*c.* 947) [6] referred to the value of the windmill, as did Al-Istakhrī a little later; and a full description was given by Al-Dimashqī in the thirteenth century: 'The inhabitants use the wind for turning the mills and for the removal of sand from one place to another. They erect a high building like a minaret; or they use a high summit of a mountain or a similar prominence or a tower of a castle, and upon this raise up a building. In the building is a mill which revolves and grinds, while below is a toothed wheel which is caused to rotate by the useful action of the wind. The wheel rotates below, thereby driving the mill above'. Windmills were also used to raise water from wells in order to irrigate the gardens. Whereas water-mills are mentioned in Vitruvius, Book X, Chap. 10, and were perhaps invented in the time of Augustus, it seems likely that the windmill was an Islamic application of later date. The latter was certainly referred to by Al-Mas'ūdī as though its use were commonly accepted in Afghanistan. It is possible that the windmill was known in Arabia as early as the first half of the seventh century A.D.

REFERENCES

[1] Hauser, F. Das Kitāb al-ḥiyal. *Abh. Gesch. Naturw. Med.*, 1922.

[2] Lugal, N. and Sayili, A. Farabi's article on vacuum. Ankara. 1951.

[3] Coomaraswamy, A. C. The treatise of Al-Jazarī on Automata, Boston. 1924.

[4] Khanikoff, N. *J. Amer. Orient. Soc.*, **6**, 1, 1860.

[5] Wiedemann, E. Zur Mechanik u. Technik bei den Arabern. *S.B. phys.-med. Soz. Erlangen*, **38**, 1, 1906. *Idem.* Zur Technik bei den Arabern. *Ibid.*, **38**, 307, 1906.

[6] de Meynard, C. Barbier, and de Courteille, Pavet. Les Prairies d'Or, II, 80. (Société Asiatique, 9 vols.), Paris. 1861–77.

Vitamin B_{12}

A. W. JOHNSON and SIR ALEXANDER TODD

The successful isolation and identification of the anti-pernicious-anaemia factor, vitamin B_{12}, has been the outcome of a combined effort by biologists, chemists, and crystallographers. Beginning at the recognition in 1926 of the therapeutic value of liver in the treatment of pernicious anaemia, the main features of the story of vitamin B_{12} are here described up to the announcement of the total structure in 1955. This structure strongly suggests that the vitamin is related to haem, chlorophyll, and other natural porphin derivatives.

In an important paper published in 1926, G. R. Minot and W. P. Murphy [1] reported that whole liver was effective in the dietary treatment of pernicious anaemia. From that time onwards many groups of chemists and biochemists subjected liver extracts to chemical fractionation in attempts to isolate the active principle, but it was not until 1948 that the pure anti-pernicious-anaemia (APA) factor, now known as vitamin B_{12}, was isolated independently and almost simultaneously by K. Folkers and his colleagues [6] in the laboratories of Merck and Company Inc. in America and by E. Lester Smith and his associates [3, 5] of Glaxo Laboratories Limited in England. The early work, which resulted in several commercial preparations of liver concentrate appearing on the market, has been summarized by Y. Subba Row, A. B. Hastings, and M. Elkin [2], who emphasize the diversity of the views held at different times on the nature of the anti-pernicious-anaemia factor. During the period up to 1945 covered by their review, the amount of material needed per day by a patient suffering from the disease decreased from 400 grams to less than one milligram as concentrates improved in quality, and the authors stated that the isolation and identification of the active material might reasonably be expected to be an attainable object. Many early workers in the field held the view that the factor was protein or polypeptide in nature, although later the opinion was expressed by some that it might be a compound related to the pterins, a group of substances which had been shown to occur in the wings of a variety of insects. The discovery of the folic acid group of vitamins at first seemed to support this view, but liver concentrates were eventually prepared which were effective in smaller doses than pure folic acid in the types of anaemia for which this substance had activity.

Probably the main reason for the long period which elapsed before the factor was finally isolated was the lack of a rapid and reliable method of bioassay; no animal test was discovered giving results parallel to those of clinical studies in man. Indeed, in their final isolation procedure the British workers [3] used clinical assay almost exclusively for testing concentrates. The American group, however, utilized an important observation by M. S. Shorb [4] that the anti-pernicious anaemia factor of liver is also a highly active growth-factor for the organism *Lactobacillus lactis* Dorner, and they were able to develop a microbiological method of assay. Microbiological methods are now used almost universally for assay purposes, although other micro-organisms are now recommended, such as, among others, *L. leichmannii* 4797 or 313. When finally isolated as a deep red crystalline solid, and tested for activity in the clinical treatment of pernicious anaemia, positive responses were obtained with the vitamin in a dosage of 0·5–5 micrograms daily. Vitamin B_{12} is thus one of the most potent of all physiologically active compounds. As has happened in the case of other vitamins, it was soon found that, in addition to the vitamin B_{12} isolated from liver, there appeared to be quite a number of very closely related substances in nature having varying degrees of activity. It is, in fact, appropriate to think of vitamin B_{12} as multiple in character; to this point we shall return later. The difficulties of the isolation of the vitamin from liver led to searches for other sources, and soon workers in the Merck laboratories [7] reported that it could be isolated from culture broths of *Streptomyces griseus*, the strain used for the production of streptomycin. Later work showed that members of the vitamin B_{12} group of compounds were present as by-products in the waste liquors resulting from the production of a number of other antibiotics, such as neomycin and chloromycetin, but today it is more usual to employ a special fermentation for the production of the vitamin; *Bacillus megatherium* and *S. olivaceus* have been recommended as particularly suitable organisms for this purpose. The idea that the vitamin normally has a microbiological origin has received further support from the discovery that appreciable quantities of it and related compounds are present in sewage sludge. Sewage sludge has indeed been considered as a possible starting material for commercial production of vitamin B_{12}, although the separation of the closely related substances present in it might prove to be costly and time-consuming. Seaweed also is rich in the vitamin, although here again it has been shown that it is synthesized by micro-organisms and merely concentrated by the algae. The extraction of vitamin B_{12} from these various sources, where it occurs in extremely low concentrations, is a multi-stage procedure generally involving solvent extraction, adsorption, and chromatography. The extensive use of such solvents as phenol and benzyl alcohol has been a noteworthy feature of the large-scale isolation methods.

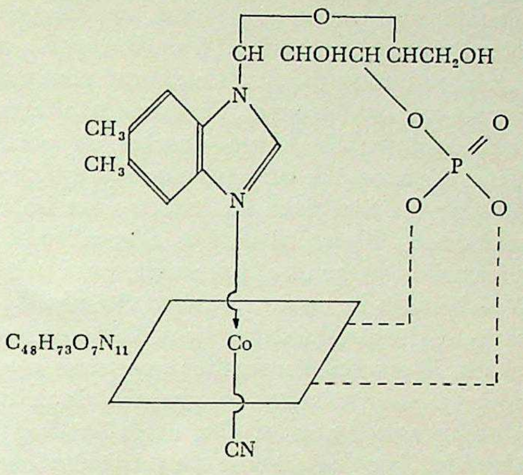
A great deal of research has been carried out to determine the biological functions of vitamin B_{12}, and although much remains to be done several apparently unrelated biochemical problems have already converged on this new member of the vitamin B group. One of these problems concerns the so-called animal protein factor. The fact that animal protein contains a growth factor which is not present in vegetable protein has been recognized for some time, but the problem was revived during the last war, when the scarcity of animal protein caused the introduction of a higher proportion of soya bean meal into poultry feeds. The unknown factor was shown to be present in cow manure and also in poultry droppings after, but not before, incubation, thus suggesting that the factor was formed through the intervention of micro-organisms. American workers in the Lederle Laboratories [8] were the first to demonstrate that the anti-pernicious-anaemia factor of liver was the main component of the animal protein factor when they produced concentrates from bacterial cultures obtained from hen faeces which were active in both senses. The growth-promoting properties of crystalline vitamin B_{12} for rats and chicks was originally described in 1948, but it has since been demonstrated that less of the vitamin is required in the presence of certain antibiotics, e.g. aureomycin and penicillin. Concentrates of vitamin B_{12} are very widely used today as feed supplements for pigs and poultry, only a few milligrams being required per ton of foodstuff. Although many of the ambitious claims for certain therapeutic applications of the vitamin should be treated with reserve, all the early successes in the treatment of pernicious anaemia have been fully confirmed. An interesting consequence of one aspect of this work has been the elucidation of the relation of vitamin B_{12} to the anti-anaemia factors of W. B. Castle [9], who had shown that there was a thermostable substance, the extrinsic factor, present in certain foods, which produced a response in pernicious anaemia patients only when administered with normal gastric juice; the latter was said to contain the intrinsic factor. The extrinsic factor is now known to be identical with vitamin B_{12}, and the intrinsic factor is a protein recently claimed [10] to have been prepared in a very concentrated form. There is as yet no evidence for a chemical reaction between vitamin B_{12} and the intrinsic factor, which seems to differ from the so-called B_{12}-binding proteins which have also been purified. Apart from its anti-anaemic and nutritional functions, vitamin B_{12} plays an important role in the reduction of disulphide groups and in the biosynthesis of labile methyl groups, e.g. in the biosynthesis of methionine from homocystine and of choline from glycine, although probably it does not participate directly in transmethylation.

Vitamin B_{12} crystallizes from aqueous acetone or hot water as beautiful dark-red hydrated crystals with the formidable molecular formula $C_{63}H_{90}O_{14}N_{14}PCo$. A unique feature of the molecule is the presence in it of a cobalt atom, and magnetic measurements indicate that the cobalt is in the trivalent state; no cobalt-containing organic compounds other than members of the B_{12} group have yet been found in nature. The vitamin as isolated is a weak base, and its characteristic ultra-violet and visible absorption spectra are not greatly affected by changes in *p*H. Very soon after the isolation of vitamin B_{12} it became apparent that a number of closely related substances existed, all possessing comparable biological activity, and their inter-relation became clear when vitamin B_{12} was found to contain a cyanide group directly attached to the cobalt atom. The cyanide group was detected both by its chemical and its physical behaviour, and it could be replaced without difficulty by any one of a variety of other groupings. For example, substitution of the cyanide by hydroxyl gave rise to vitamin B_{12a} (*or* B_{12b}), and substitution by nitrite gave vitamin B_{12c}. These compounds can be reconverted to vitamin B_{12} by treatment with cyanide ions. In order to simplify the nomenclature, vitamin B_{12} is now officially designated cyanocobalamin; B_{12a}

is hydroxocobalamin; B_{12c} is nitritocobalamin; and several other members of the group have been described. They can be distinguished by their chromatographic behaviour and by their partition coefficients in various solvent mixtures.

Further knowledge of the chemical structure of the vitamin came from studies of its acid hydrolysis. This phase of the work was carried out on very limited amounts of material, and considerable use was made of chromatography on paper for the examination of microquantities of reaction products. When the vitamin was heated with concentrated hydrochloric acid at 150° for several hours there were produced, in addition to ammonia (five to six molecules per molecule of vitamin) and phosphoric acid, a red cobalt-containing resin and two further products which were detected by paper chromatography. The first of these was a base which gave a blue coloration with ninhydrin and which eventually proved to be Dg-1-amino-2-propanol (one molecule per molecule of vitamin). The other compound, also a base, was detected by its fluorescence in ultraviolet light and proved to be 5:6-dimethylbenziminazole. Less drastic hydrolysis of the vitamin gave two N-substituted 5:6-dimethylbenziminazoles, designated the α- and β-components respectively. Further hydrolysis of the α-component gave first the β-compound and then 5:6-dimethylbenziminazole itself. All three of these degradation products have been isolated, and their structures have been determined and confirmed by synthesis. The β-compound is the N-α-D-ribofuranoside of 5:6-dimethylbenziminazole and the α-component is the corresponding 3′-phosphate, so that the α- and β-components can be regarded as benziminazole analogues of the purine nucleotides and nucleosides. It is of some interest to note, however, that these benziminazole glycosides have the α-configuration, whereas the natural purine nucleosides are uniformly β-glycosides.

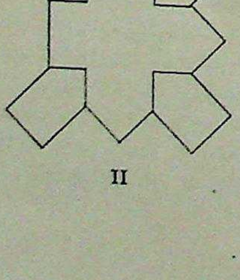
The addition of excess cyanide to vitamin B_{12} causes the formation of a purple complex containing two cyanide groups, and a careful examination of the ultra-violet absorption spectrum of this compound suggested that in the parent vitamin the second nitrogen of the benziminazole ring system is connected to the cobalt atom by a co-ordinate bond. The evidence presented so far, which was accumulated by K. Folkers and his colleagues in the laboratories of Merck and Company Inc.; by A. R. Todd, A. W. Johnson, and their co-workers at Cambridge; by V. A. Petrow and his group at British Drug Houses Limited, and by E. R. Holiday at the Medical Research Council Spectroscopy Unit, lead to the partial structure (I) for the vitamin.



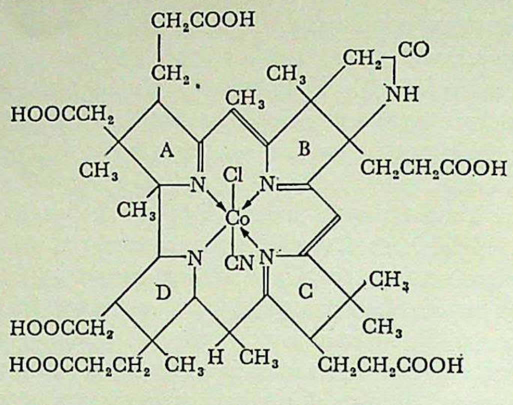
I

Investigations of other microbiological sources of vitamin B_{12} led to the discovery of a second group of related compounds isolated from fermentation liquors, sewage sludge, etc., which differed from vitamin B_{12} in that they did not contain 5:6-dimethylbenziminazole as the basic component of the nucleotide. Natural members of the B_{12} group in which 5:6-dimethylbenziminazole has been replaced by adenine, 2-methyladenine, and 2-methylhypoxanthine have been described, and other bases have been introduced into the molecule by microbiological synthesis in the presence of appropriate precursors. In general, these compounds have low animal activity and varying activity as growth factors for micro-organisms. Apart from the nucleotide, the remainder of the vitamin B_{12} molecule, the so-called Factor B, is common to all these compounds, and indeed Factor B itself has been isolated from fermentation liquors and from calf manure as well as from the products of brief hydrolyses of vitamin B_{12} with warm acids.

The ammonia which is liberated during hydrolyses of the vitamin is now known to be derived from primary amides, and chemical evidence has been presented to show that there are certainly four, and probably six, primary amide groupings in vitamin B_{12}. In addition, the aminopropanol is bound amide-wise through the nitrogen atom, so that there are potentially seven carboxyl groups present in the central cobalt-containing portion of the molecule. In fact, the red resinous product obtained upon hydrolysing the vitamin is an acidic mixture, the complexity of which was not fully appreciated until the technique of electrophoresis on paper was applied [11]. Two series of acids were then recognized, one lacking the nucleotide and containing from one to seven carboxyl groups (i.e. derived from Factor B), and the other retaining the nucleotide and containing one to six carboxyl groups. Further complications were caused by the large number of possible isomers; for example, three monocarboxylic acids containing the combined nucleotide were isolated in substance. These, as well as a number of di- and tricarboxylic acids of this series, were isolated and each could be re-converted to vitamin B_{12} by re-forming the amides from the acids by orthodox methods. However, for further structural investigations it was desirable to prepare, in a pure crystalline state, one of the acids lacking the nucleotide. For this purpose the mixture of penta- and hexacarboxylic acids obtained from a hydrolysis of the vitamin with 30 per cent aqueous sodium hydroxide at 150° was selected. Separation of these acids on a relatively large scale was achieved by application of anion-exchange chromatography, and a pure hexacarboxylic acid, obtained as its monochloride-monocyanide, was eventually induced to crystallize [12]. This was the first crystalline degradation product, not containing the combined nucleotide, to be prepared from vitamin B_{12}. It had a molecular formula $C_{46}H_{60}O_{13}N_6CoCl.2H_2O$ and possessed a visible spectrum very similar to that of the parent vitamin, indicating that the chromophore had not undergone any marked change. The crystalline acid was submitted to Dr D. C. Hodgkin at Oxford for crystallographic examination, and she and her colleagues were able to construct the general pattern of the nucleus (II) surrounding the cobalt atom [13]. This pattern was identical with that already found by Dr Hodgkin in the molecule of vitamin B_{12} itself and provided welcome confirmation of this novel macrocyclic ring system which, although reminiscent of that found in the natural porphyrins, differed strikingly in that two of the four rings present were joined together directly rather than by way of an intermediate carbon atom.

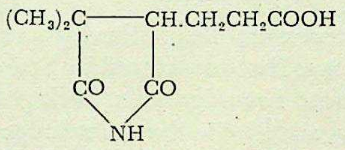


II



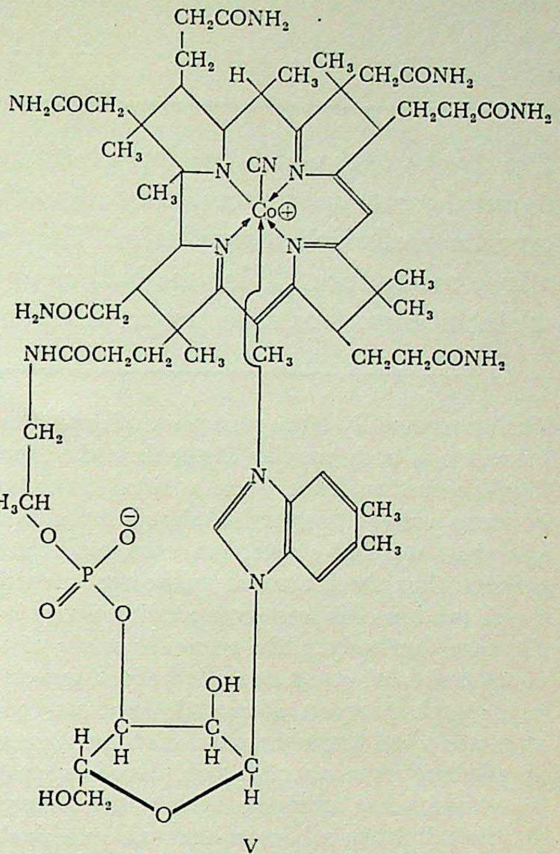
III

Soon afterwards the relative positions of all the atoms, excluding hydrogen, were deduced by a brilliant piece of X-ray analysis by Dr Hodgkin and her colleagues, and, taking into account the known chemical properties of the compound, structure (III) was deduced [14]. Of the six acidic groups, four were present as propionic acid residues and the other two as acetic acid residues, all of them being attached to the β-positions of the five-membered rings. The additional five-membered ring fused to ring B of the central nucleus was formulated as a lactam because of its stability to alkali. The eight single-atom side chains were all formulated as methyl groups to conform to the chemical analysis, assuming that some of the oxygen in the crystalline material was present as water of crystallization, as found in the crystal structure. The double-bond arrangement, formulated as shown on the basis of X-ray and chemical evidence, is still tentative and may be the subject of slight revision. Independent chemical evidence supporting the structure of ring C as formulated in (III) was provided by the isolation of the succinimide (IV) from oxidations of a crude vitamin B_{12} hydrolysate by the Merck group of workers [15]; the production of the same product from the pure hexacarboxylic acid was later confirmed at Cambridge. Once structure (III) had been established, the electron density patterns for crystals of vitamin B_{12} itself became easier to interpret. It appeared from these patterns that the vitamin did not contain a five-membered lactam ring fused to ring B but that, instead, this ring bore in one β-position a methyl and an acetamide residue and in the other a propionamide residue. Also, the cyanide in the vitamin was attached at the side of the cobalt atom opposite to that of the cyanide group in the hexacarboxylic acid. The aminopropanol was attached to the propionic acid side-chain of ring D and the phosphate was substituted only by the nucleoside and by the aminopropanol, as had already been deduced from the stability of the phosphate linkage. Accordingly the molecule was formulated as a zwitterion, the negative charge of the phosphoric acid being balanced by a net positive charge on the cobalt atom. With these additional facts it is possible to derive the complete structure (V) of vitamin B_{12}, although the precise location of the double-bond system, assigned largely on the basis of the behaviour of the vitamin on chlorination experiments, is still in some doubt. Further work is necessary to clarify this point, which does not, however, affect the main structural picture.



IV

It would seem more than coincidence that the arrangement of propionic and acetic acid side-chains in (V) corresponds to that of uroporphyrin III, for which a biogenetic scheme has been demonstrated [16]. A modification of this scheme [14] has been suggested which could give rise to the nucleus of vitamin B_{12}, and at the same time it suggests methods by which synthetic approaches to this complex molecule might be formulated.



V

Viewed in the light of this suggestion, the extraordinary complexity of the vitamin B_{12} molecule is somewhat mitigated, since it can be regarded as a not too distant relative of the natural porphin derivatives such as haem and chlorophyll, which are found widely in nature.

REFERENCES

[1] Minot, G. R. and Murphy, W. P. *J. Amer. med. Ass.*, **87**, 470, 1926.

[2] Subba Row, Y., Hastings, A. B., and Elkin, M. *Vitam. and Horm.*, **3**, 237, 1945.

[3] Fantes, K. H., Page, J. E., Parker, L. J. F., and Lester Smith, E. *Proc. roy. Soc.*, B, **136**, 592, 1950.

[4] Shorb, M. S. *J. biol. Chem.*, **169**, 455, 1947; **176**, 1463, 1948.

[5] Lester Smith, E. *Nature, Lond.*, **161**, 638, 1948; **162**, 144, 1948.

[6] Rickes, E. L., Brink, N. S., Koniuszy, F. R., Wood, T. R., and Folkers, K. *Science*, **107**, 396, 1948; **108**, 134, 1948.

[7] *Idem. Ibid.*, **108**, 634, 1948.

[8] Stokstad, E. L. R., Page, A., Pierce, J., Franklin, A. L., Jukes, T. H., Heinle, R. W., Epstein, M., and Welch, A. D. *J. Lab. clin. Med.*, **33**, 860, 1948.

[9] Castle, W. B., Rose, J. B., Davidson, C. S., Burchenal, J. H., Fox, H. J., and Ham, T. H. *Science*, **100**, 81, 1944.

[10] Latner, A. L. *Biochem. J.*, **59**, xxviii, 1955.

[11] Armitage, J. B., Cannon, J. R., Johnson, A. W., Parker, L. J. F., Lester Smith, E., Stafford, W. H., and Todd, A. R. *J. chem. Soc.*, 3849, 1953.

[12] Cannon, J. R., Johnson, A. W., and Todd, A. R. *Nature, Lond.*, **174**, 1168, 1954.

[13] Brink, C., Hodgkin, D. C., Lindsey, J., Pickworth, J., Robertson, J. H., and White, J. G. *Ibid.*, **174**, 1169, 1954.

[14] Hodgkin, D. C., Pickworth, J., Robertson, J. H., Trueblood, K. N., Prosen, R. J., and White, J. G. *Ibid.*, **176**, 325, 1955;
Bonnett, R., Cannon, J. R., Johnson, A. W., Sutherland, I. R., Todd, A. R., and Lester Smith, E. *Ibid.*, **176**, 328, 1955.

[15] Kuehl, F. A., Shunk, C. H., and Folkers, K. *J. Amer. chem. Soc.*, **77**, 251, 1955.

[16] Rimington, C. *Endeavour*, **14**, 126, 1955.

Shock waves in air

E. W. E. ROGERS

The shock waves which develop when gases move at speeds greater than that of sound have assumed great importance in the design of aircraft, and they have been intensively studied both experimentally and theoretically. They are also significant in other connections; thus they offer a means for studying the behaviour of gases at temperatures otherwise unattainable in the laboratory. The main properties of shock waves and their significance are here reviewed.

The unexpectedly large resistance of the air to the passage of a body moving faster than the speed of sound seems to have been noticed first during gunnery trials with spherical shot in 1742. Nearly 150 years were to elapse, however, before it was realized that the increased resistance was due to the formation of intense compression waves in the air near the body. The scientific study of these compression waves (now called shock waves) has made such progress during the present century that when the first controlled flight at supersonic speeds in a piloted aircraft took place in 1947 (only forty-four years after the Wright brothers made the first flight in a heavier-than-air machine) the behaviour of the aircraft was similar to that predicted from laboratory tests.

Shock waves are characteristic of gas motion at supersonic speeds, and cannot arise when the motion is everywhere at a speed lower than that of sound. Since a sound wave can be regarded as an infinitely weak shock wave, the velocity of sound is a convenient standard with which to compare the velocity of a shock wave. In the simple theory for the propagation of a sound wave it is generally assumed that the accompanying changes of the air density and pressure are very small and that the form of the wave is unaltered with time. When the amplitude of the pressure disturbance is no longer small, however, the wave may change in form as the disturbance progresses [1], the high-pressure region of the wave travelling more quickly than that having a lower pressure. Eventually the low-pressure region is overtaken, and the pressure rise then occurs almost discontinuously through a very steep 'front'; the disturbance has become a shock wave (figure 1).

The shock wave advances into the undisturbed air at a velocity greater than that of a sound wave, but because of the temperature increase accompanying the pressure rise, the velocity of the shock relative to the air left behind it is below the speed of sound for that region. The opposite type of wave, in which the pressure decreases through a very steep front, can never be formed; such a wave would be unstable and would rapidly change in form.

The pressure discontinuity possible in wave motion was first considered by Stokes in 1848, and subsequent investigations during the nineteenth century added to the knowledge of what was regarded as an interesting phenomenon, even if of only academic significance. By 1910, however, when the subject was very fully discussed by Rayleigh [2], knowledge of the production of shock waves by high-speed projectiles and by explosions was firmly established, and in subsequent years research increased as the importance of shock waves in the aerodynamics of aircraft, missiles, and rotating machinery, in detonation problems, and in combustion thermodynamics became apparent.

Shock waves behave differently from some other types of waves, such as sound, light, and electromagnetic waves. For example, the excess pressures caused by interfering sound waves are additive; the interaction and reflection of shock waves, on the other hand, can lead to very large pressure increases [3]. This difference in behaviour is due to the non-linear form of the differential equation governing the formation and propagation of shock waves, a form which makes the mathematical analysis rather complex.

For the practical problems in which shock waves occur it is usually sufficient to regard them as simple discontinuities in the characteristics of a

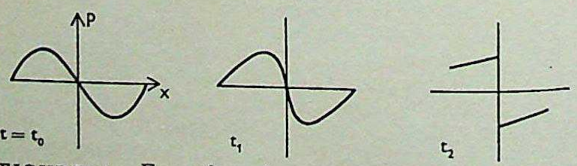


FIGURE 1 – *Formation of a pressure discontinuity in a large-amplitude pressure wave propagating in a perfect gas.*

perfect fluid. In a real fluid, such as air, the steepening of the pressure front with progression of the wave (figure 1) is resisted by the diffusive action of viscosity and heat conduction, and as a result the pressure gradient in the fully developed compression wave remains finite, though large. The shock wave then has a definite thickness and structure, and this has been much studied in recent years, both from the viewpoint of the kinetic theory of gases and from that of a continuous fluid. This work is referred to briefly later.

SHOCK WAVES IN STEADY AIR FLOWS

To an observer moving with the shock wave the air appears to approach the wave at a supersonic velocity and to recede from it with a velocity less than that of sound for the region to the rear of the wave. A shock wave which is inclined to an approaching supersonic air stream behaves similarly to the velocity component normal to the wave front but leaves unaltered the velocity component along the front. Thus an inclined shock wave reduces the resultant flow velocity of the stream by some amount, usually leaving it still supersonic, and in addition turns the flow abruptly through an angle. Thus the sudden deflection of a supersonic stream by a solid boundary will be accomplished in regions away from the boundary by an inclined shock wave of the appropriate inclination and strength (figure 2). A subsonic stream approaching the corner would change direction gradually with none of the sudden alteration of direction and velocity characteristic of supersonic flow.

Since shock waves caused by the high-speed flight of bodies are of considerable practical importance, it is of interest to see how these arise. For convenience the body will be considered as stationary in a moving air stream; because it causes a disturbance in this stream, the air is both accelerated and retarded in the neighbourhood of the body. At one particular subsonic value of the stream speed the velocity of sound will be reached at some position on the model surface, and a further increase in stream speed then causes a local supersonic flow region to occur adjacent to the model. While the air can be accelerated smoothly to supersonic speeds by the body's curved surfaces, the subsequent retardation back to subsonic conditions is inherently unstable and is accomplished instead by means of a normal shock wave; this wave marks, therefore, the rear end of a local supersonic flow embedded in the subsonic stream.

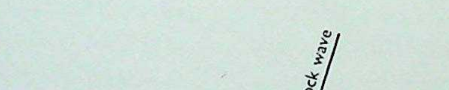


FIGURE 2 – *Deflection of flow by a shock wave.*

As the stream speed approaches that of sound the normal shock wave moves back to the rear of the body, and when the stream speed is just supersonic a bow shock wave appears in the stream ahead. This bow wave renders the flow between it and the body subsonic, and can therefore be regarded as the limit to which the pressure disturbances caused by the model can be transmitted upstream. With a further increase in stream speed the bow wave approaches the body and the intermediate subsonic region diminishes. If the nose of the body is sharp, the bow shock wave subsequently attaches to it and is then inclined at the appropriate angle for deflecting the flow past the model in a way similar to that shown in figure 2. Further increases in the stream speed merely reduce the angle between the shock waves and the direction of the undisturbed flow, and at very high supersonic speeds the bow wave will lie close to the body surface. This complete sequence of shock wave growth and movement is depicted diagrammatically in figure 3.[1]

When the flow round the body has regions of both subsonic and supersonic flow, the position and strength of the shock waves are very difficult to predict theoretically if only the body shape and the stream speed are given. This mixed type of flow occurs in the so-called transonic region when the stream speed is near that of sound. For aircraft this speed range is of great importance, and information about shock wave effects and the

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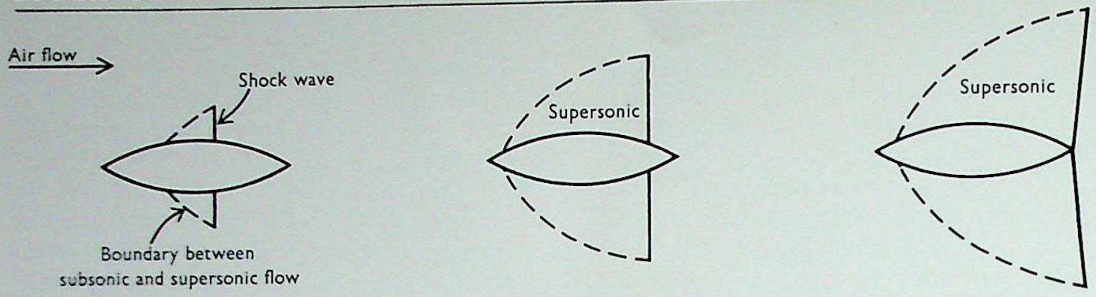
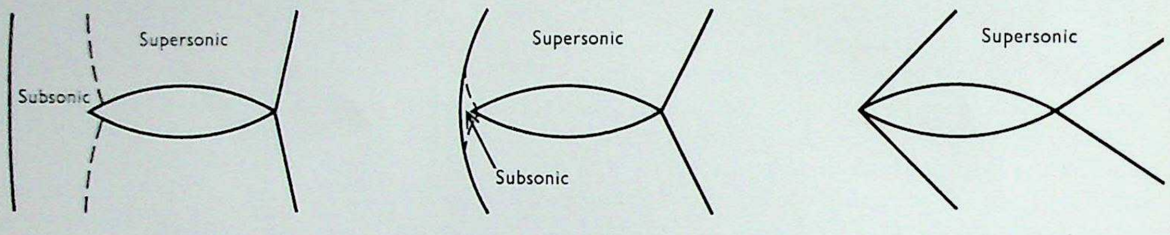
[1] The similarity between wave patterns shown in figure 3 at supersonic speeds and the surface wave pattern caused by a ship when this is viewed from above is not entirely fortuitous. The motion of a free water surface when the water depth is very shallow is in fact equivalent to the wave motion caused by a similar disturbance in a gas if the ratio of the specific heats of the gas is 2; for air the ratio is 1·4.



(*a*) Shock wave just formed at subsonic stream speed.

(*b*) High subsonic stream speed.

(*c*) Just below the speed of sound.



(*d*) Just above speed of sound.

(*e*) Low supersonic stream speed.

(*f*) Moderate supersonic stream speed.

FIGURE 3 – *Diagrams of shock-wave growth and movement for a typical body immersed in a steady air stream.*

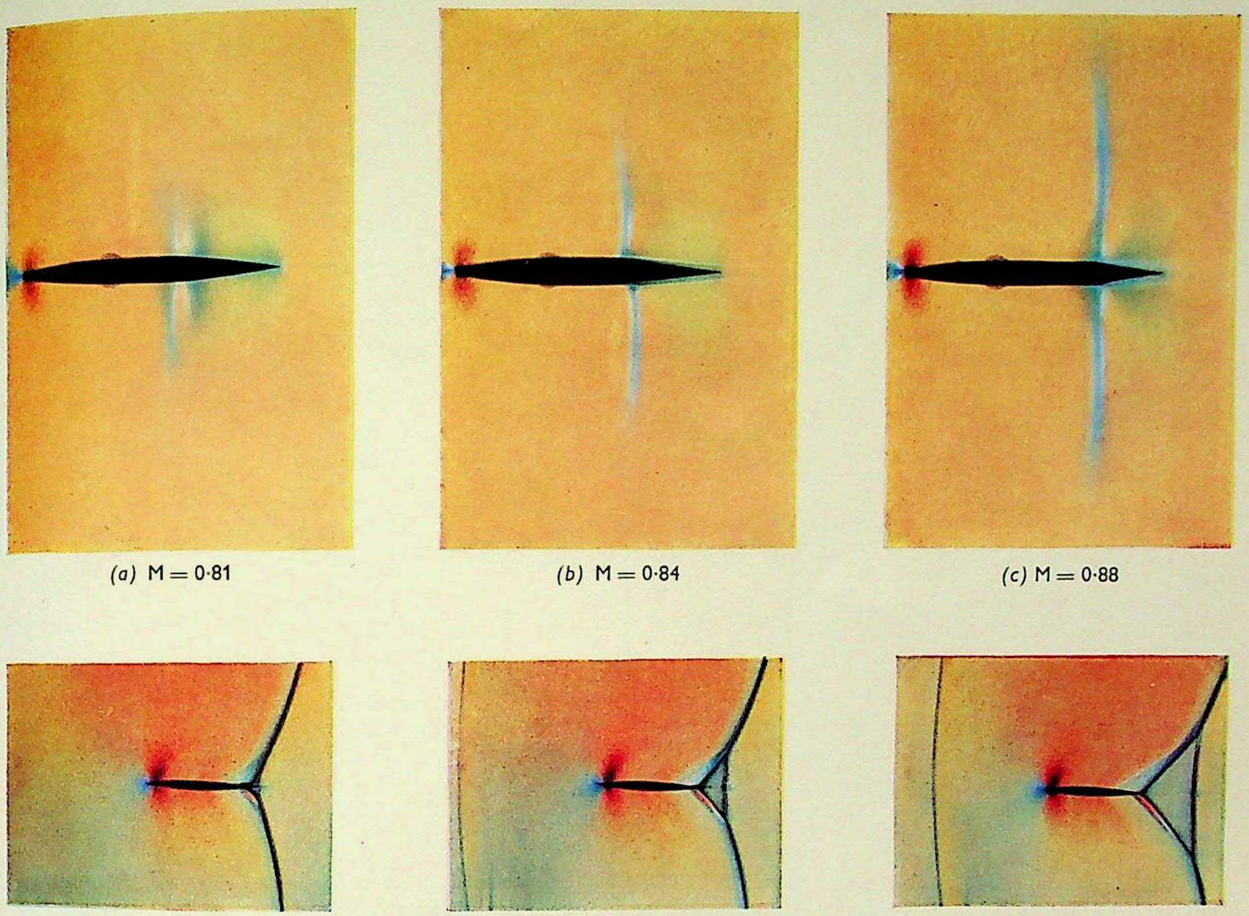
resulting behaviour of a body at such speeds is usually obtained experimentally either from models in free flight or from stationary models held in the air stream of a wind tunnel. The latter arrangement has many obvious advantages.

For a wholly supersonic flow field the mathematical analysis is rather easier, and in recent years much progress has been made in predicting the position and strength of the expected shock waves. The theoretical results have been largely substantiated by experimental data, obtained from both free-flight and wind-tunnel tests.

The free-flight technique is widely used by ballisticians. As early as 1886 Ernst Mach [4, 5] obtained a photograph of a bullet in flight at about 1·5 times the speed of sound; this clearly showed the inclined shock waves originating from the nose of the bullet, a flow pattern which Mach had expected on theoretical grounds. Because of his pioneer work in studying the problems of high-speed flight, the ratio of the model velocity (or alternatively the fluid velocity if the model is stationary relative to the observer) to the local speed of sound is usually called the Mach number of the motion, designated by M. Figure 6 shows a modern photograph of a projectile in flight at a Mach number of 2·51. The shock waves, being regions of intense density gradients, refract the light issuing from a short-duration spark and hence appear as shadows (with adjacent bright bands) on a photographic plate placed on the far side of the projectile from the spark. The width of these shock-wave shadows depends mainly on the geometry of the apparatus and is not related to the actual shock-wave thickness; this remark, it should be noted, applies to all the flow photographs shown in this article.

In the wind tunnel a uniform air stream is created and made to flow past a stationary model at speeds up to about nine times that of sound; the shock pattern caused by the model can then be studied visually or by means of suitable exploring gear. This is usually a far more convenient method for obtaining information than by means of a model in flight, and is very widely used.

The working section of the wind tunnel where the model is placed may vary in size, from tunnel to tunnel, from a few square inches in cross-section to many square feet; the corresponding model size will also vary, and for the larger tunnel the model may be several feet in span and length, thus allowing considerable detail to be represented if this is required. Large, modern high-speed wind tunnels are complex pieces of equipment, perhaps



(a) M = 0·81 (b) M = 0·84 (c) M = 0·88

(d) M = 0·95 (e) M = 1·03 (f) M = 1·08

FIGURE 4 (a) *to* (f) – *Colour* Schlieren *photographs of flow around model wing section at subsonic and transonic Mach numbers.* (*Air flow from left to right.*)

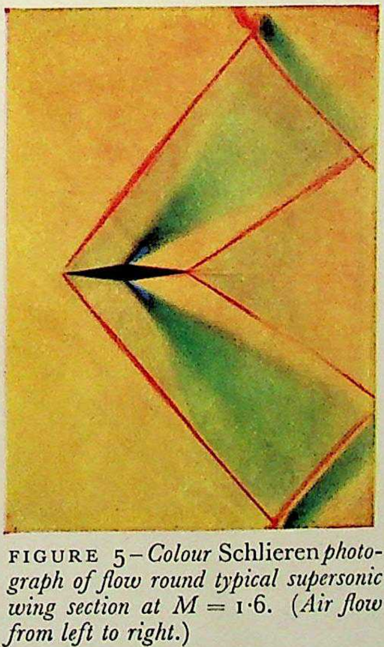


FIGURE 5 – *Colour* Schlieren *photograph of flow round typical supersonic wing section at M* = 1·6. (*Air flow from left to right.*)

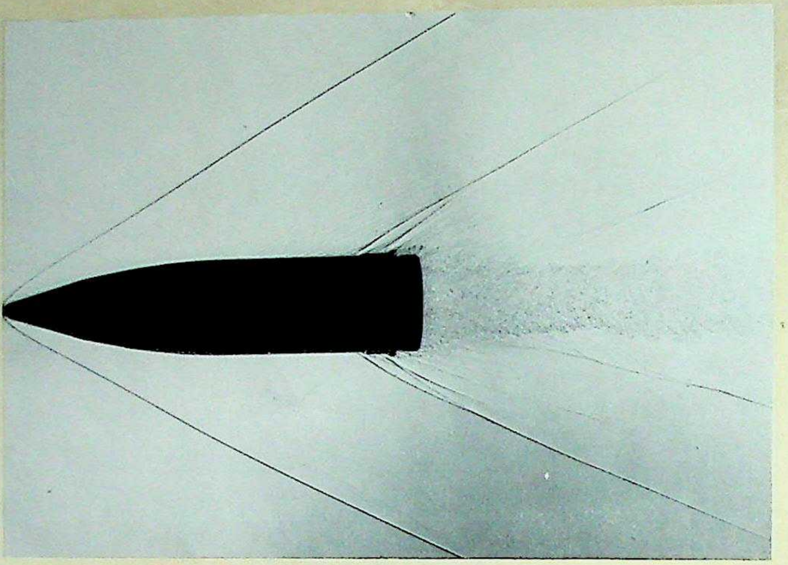
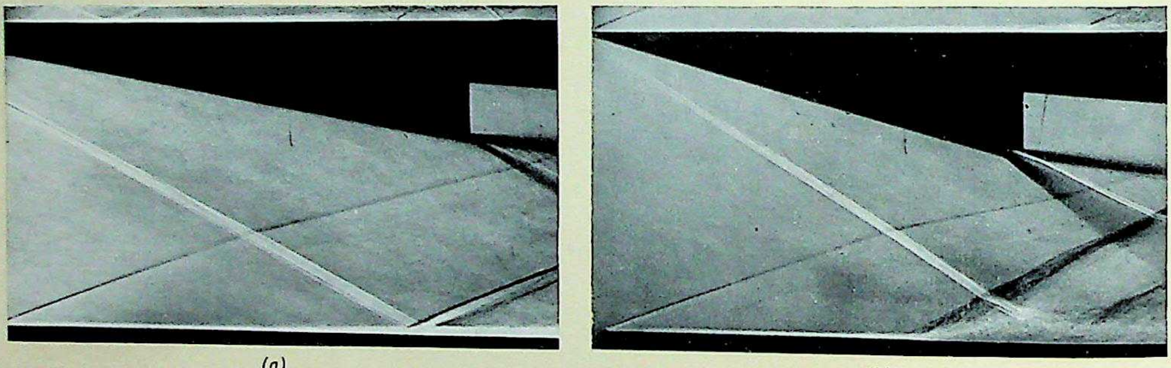


FIGURE 6 – *Shadow photograph of projectile in flight at* $M = 2{\cdot}51$.



(a) (b)

FIGURE 7 – *Reflection of shock waves from flat plate at* $M = 3$, *showing different types of interaction between the shock wave and the plate boundary layer* (Schlieren *photographs; air flow from left to right*). (a) *Reflection of weak shock.* (b) *Reflection of strong shock.*

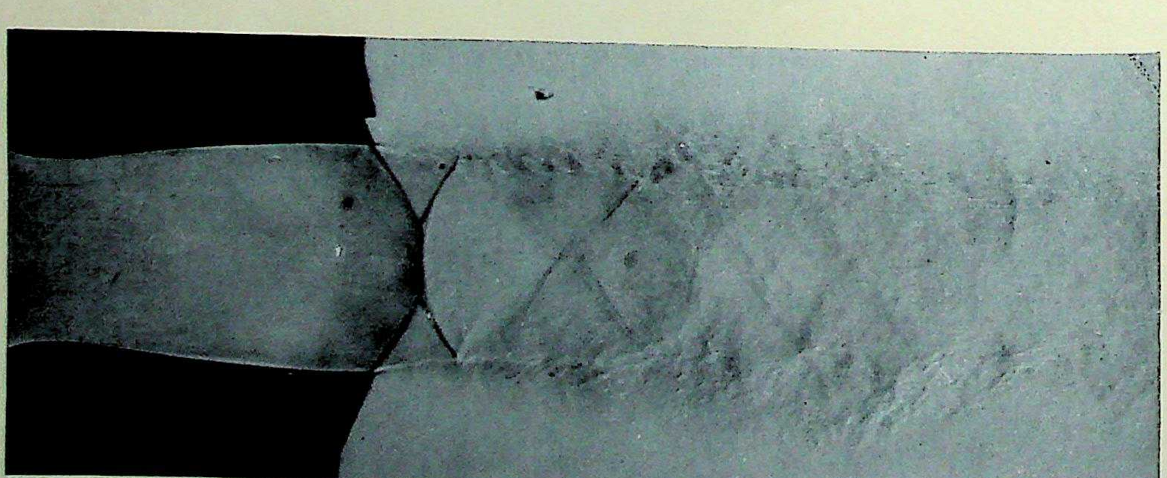


FIGURE 8 – *Shock waves in air jet issuing at* $M = 1{\cdot}43$ (Schlieren *photograph*).

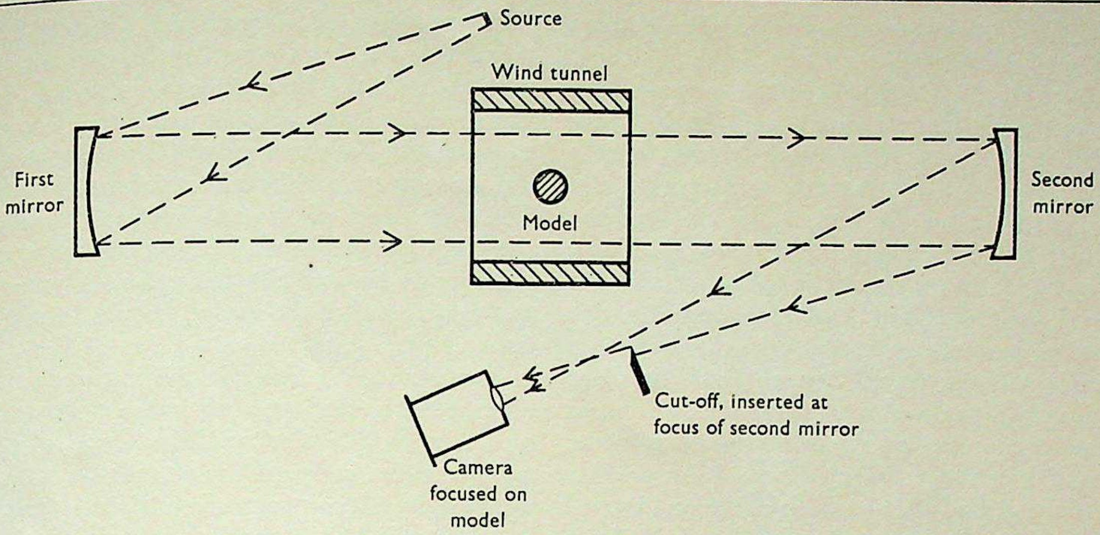


FIGURE 9 – Schlieren *optical method as used for wind tunnel.* (*Flow in tunnel normal to plane of paper.*)

costing millions of pounds to build and requiring several thousands of horse-power to provide the air stream. The air is driven past the model either by some form of fan or axial air compressor or by compressed air injected at high speed through narrow slots in the tunnel wall downstream from the model position. Such tunnels can usually be run either continuously or for long enough for the finite duration of the run to be unimportant. For achieving Mach numbers of above about 4 in the working section it is often more convenient to exhaust a high-pressure air receiver to atmosphere through the working section or to fill an evacuated vessel from the atmosphere, the working section being placed on the inlet pipe to the vessel. The duration of the run with these types of tunnel is small, often only a few seconds, and care must be taken with the instrumentation in order to obtain accurate information in this limited time.

As the air is accelerated into the working section of the tunnel its temperature is reduced, and this reduction is sufficient to cause condensation of the oxygen and nitrogen present in the air when the Mach number in the working section is above about 4·5 unless the slow-moving air awaiting entry to the working section is heated well above the normal atmospheric temperature.

The shock waves from the model in the tunnel air stream can be demonstrated optically in a manner similar to that used for the photograph of the projectile in figure 6. Alternatively, interferometers, usually of the Mach-Zehnder type, can be used to give the density field around the model; the air density can also be measured directly by determining the absorption of X-rays passed through the flow in the tunnel at the model position. The most important method, however, is that adapted by Mach from its original use by Toepler for investigating imperfections in optical mirrors. Because of this origin it is known as the *Schlieren* (or, more rarely, the striation) method [6]. The optical arrangement usually employed for wind tunnels is shown in figure 9; the light, refracted by changes in the fluid density near the model, is deflected either on to or away from the cut-off inserted at the focus of the second mirror. The direction of the deflection depends on the sign of the particular density gradient causing the optical disturbance, and the changes in illumination in the image of the flow field obtained in the camera are proportional to these density gradients.

With a monochromatic light source the shock waves appear as either light or dark bands on a grey background. Alternatively, a small spectrum can be used as a light source, and the refraction effects can then be made to give colour changes on either side of the position in the spectrum of the background colour. This colour *Schlieren* method [7] was used to obtain figures 4 and 5. In figure 4 the model represents an aircraft wing section and completely spans the width of the wind tunnel, so that the flow does not vary across this width. The sequence of photographs shows the growth and development of the shock waves as the Mach number of the approaching air stream is increased, and thus corresponds to part of the flow changes sketched in figure 3. The shock waves in figure 4 (*a*), (*b*), (*c*) appear blue (i.e. they cause a displacement to the blue side of the background colour), and regions where the density decreases in the stream direction show up as red. The second sequence of photographs on this figure ((*d*), (*e*), (*f*)) illustrate the air flow around the same wing section at speeds close to that of sound; the background colour, however, has been chosen from a different part of the spectrum. In figure 5 the wing section is of a different shape and has the sharp leading edge necessary for allowing the bow wave to attach to the model at the Mach number of the flow (1·6). The optical system for this photograph was set up so that the colour changes obtained are the reverse of those shown in figure 4; thus the red shock waves can be clearly seen, as well as the green continuous expansion zone, shaped like a fan, which is caused by the air expanding around the shoulder of the section.

Shock waves similar to those shown in figure 5 would arise from the wing of an aircraft flying faster than sound, and in certain conditions can sometimes reach the ground, even though the aircraft itself may be manœuvring at an altitude of more than 20 000 ft. These shock waves can then be heard by an observer on the ground as sharp reports, which are generally referred to as 'sonic bangs'. Often two or more of these bangs are heard in rapid succession, and at present there is some doubt as to the true cause of these multiple bangs. They may be due to the separate shock waves associated with the wing and tail of the aircraft, or alternatively they may arise from a single wave which has become distorted during its descent to the ground and as a result of its reflection from the ground. It now seems to be agreed that the bang is due to the disturbance of the air caused by the moving aircraft and that the accumulation of noise from the engines adds only a small amount to the pressure wave that is finally heard by the observer. The intensity of the pressure wave depends on the position and flight path of the aircraft but it can be sufficiently strong to break windows locally on the ground.

The reflection of the bow shock wave from the tunnel wall can be seen in figure 5. In theory the reflected wave should be a simple compression wave, but the green zone near the point of reflection indicates that an expansion of the flow is taking place as well. The more complex nature of the reflection is caused by the narrow band of air adjacent to the tunnel wall which has been slowed down by friction effects (the wall boundary layer). The interaction between a shock wave and the boundary layer of a surface near by is of great importance and has been much studied in recent years [8]. Figures 7 (*a*) and (*b*) show respectively the interaction of a weak and a strong inclined shock (caused by the wedge at the top of the picture) with the boundary layer on a flat plate. In the second case the interaction is severe enough to cause the flow to separate from the surface of the plate upstream from the point of interaction. The refraction of a weak inclined shock wave (passing upwards from left to right) through the stronger shock, and also through an expansion fan at the rear end of the wedge, should be noticed in figure 7 (*b*).

The surface pressures in the interaction region change with the type of interaction, and can seriously modify the resultant force of the air stream on the body. If the interaction takes place near an aircraft control surface (aileron or elevator) it can cause the control to become ineffective, with perhaps disastrous results for the aircraft. The solution of this type of problem can come only from intensive wind-tunnel tests on model controls.

Another aspect of high-speed flow involving shock waves is the discharge of gas from an orifice. Figure 8 shows an air jet issuing at a Mach number of 1·43. The initial well-defined shock-wave system adjusts the pressure within the jet to that of the surrounding air, but the subsequent mixing at the jet boundary causes the jet to break up, the velocity of the air being reduced by a succession of shocks.

SPHERICAL SHOCK WAVES

Explosion waves in air can be regarded as spherical shock waves travelling outward from the site of the explosion. In such a motion the velocity is radial and, unlike the steady air flows previously discussed, the characteristics of the wave front depend on its distance from the origin and on the time that has elapsed since the explosion took place. From a knowledge of the mass of explosive used to generate the wave, the total energy available for the motion can at once be defined. The strength of the spherical shock wave (initially much stronger probably than would be encountered in high-speed flight) decreases with time, and the air which has been compressed by the passage of the shock wave is subsequently able to expand to a pressure which may be below that existing ahead of the wave. This suction phase is an important feature of wave motions caused by explosions. G. I. Taylor has discussed the problems of blast waves in some detail in [9], and has compared his theoretical results with experimental observations made during the explosion of the first atomic bomb in New Mexico in 1945.

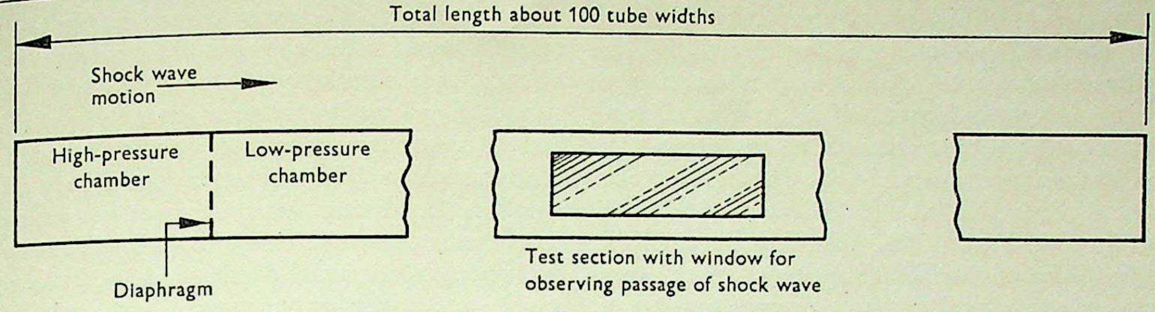

Total length about 100 tube widths
Shock wave motion
High-pressure chamber
Low-pressure chamber
Diaphragm
Test section with window for observing passage of shock wave

FIGURE 10 – *Diagram of shock tube.*

STRONG SHOCK WAVES AND SHOCK STRUCTURE

The great strength of the shock waves caused by an explosion implies that the temperature reached by the air behind the wave will be very high; in such conditions the air can no longer be expected to behave like a perfect fluid, and for this reason the study of the behaviour of strong shock waves is of considerable interest.

One method of investigating intense shock waves in the laboratory is by means of the shock tube [10] (figure 10). This consists essentially of a long uniform tube about 30 cm square, divided initially by a diaphragm into two compartments containing gas—usually air—at different pressures. When the diaphragm is ruptured, a normal shock wave moves into the low-pressure part of the tube and an expansion zone into the high-pressure region. The transient interaction of this shock wave with solid objects placed within the tube can then be studied; for example in [11] photoelastic methods were used to determine the transient internal stresses of the model.

The departures of the shock-wave behaviour from that predicted by assuming the perfect gas laws are mainly due to the variation of the specific heats with temperature and to gas dissociation and ionization, the last two effects becoming important at temperatures above about 3000° K and 5000° K respectively. Figure 11 shows the magnitude of the temperature reduction caused by these three effects as a function of the Mach number at which the shock propagates.

For large temperatures and low densities behind the shock, the time taken for the molecules of the gas to reach equilibrium after passing through the shock becomes important. The degrees of freedom associated with the molecular translation and rotation require only a few collisions to obtain thermal equilibrium, but molecular vibration and dissociation require a much larger number of intermolecular collisions for equilibrium to be established. These two modes are negligibly small at moderate densities, and the thickness of the resulting shock, the region within which the gas state is altered, is of the order of a few mean free paths. The strong shock in rarefied gases probably consists of two parts, a steep front only a few mean free paths thick, followed by a zone of greater length in which thermal equilibrium is reached between the translational and rotational degrees of freedom on the one hand and the vibrational and dissociation modes on the other.

These molecular effects occur in some gases at much less extreme conditions than is the case for air, and by a judicious choice of the working fluid information relevant to the behaviour

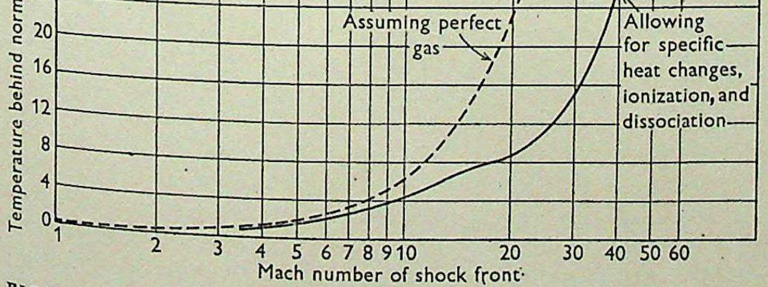


FIGURE 11 – *Theoretical temperatures reached behind strong shock waves advancing into undisturbed air at 300° K.*

of air at very high Mach numbers and low densities can be obtained in a rather easier fashion.

A strong shock wave produced in a shock tube can alternatively be regarded as a means of producing very high temperatures within a gas. In such cases the temperature to the rear of the shock can be increased by the reflection of the shock from the closed end of the shock tube, or, in a modified form of tube, by causing the shock wave to become cylindrical and to converge towards a point. Usually a single gas and not a gas mixture is studied, and temperatures up to 18 000° K have been obtained by these means [12]. At these high temperatures the shock becomes highly conducting electrically, and a band of luminosity, thought to be due to dust particles, develops behind the shock. Spectrographic studies of the shock front have also been made.

Apart from its intrinsic interest, information of this type is valuable to those studying meteors, since these can be regarded as projectiles travelling at high Mach numbers (up to say 100) in a low-density atmosphere [13], causing a strong but diffuse shock wave; not a great deal of information on this aspect of shock waves has yet been published. The problem is complicated because an allowance must be made for the evaporation of the meteor due to the high temperature behind the shock wave. It is perhaps relevant to note that, on a much larger scale, phenomena similar to diffuse shock waves are thought to occur in the rarefied gas clouds of interstellar space.

The structure of the shock wave can be investigated theoretically, either by assuming a continuous, but viscous and heat-conducting, gas or by using the kinetic theory of gases. The assumption of a continuous gas is satisfactory only for Mach numbers below about 2. At higher Mach numbers the kinetic theory of gases has generally been used, allowance being made in this way for the changes in heat conduction and viscosity coefficients with temperature. The analysis for gases like air which are not composed of single molecules is very complex [14], and simplifying assumptions often have to be made before a solution can be obtained.

Except for very low density flows, any attempt to measure the shock thickness by direct exploration methods must fail because of the very small distances involved. An elegant technique has been developed [15], however, which is based on the fact that the shock-wave thickness is about equal to the wavelength of light. The reflection of a beam of light from the front of a shock wave advancing in a shock tube can be analysed and the results compared with those predicted from theoretical models of the shock structure. The reflected light pulse is only about one-millionth of the incident light in intensity, and its duration about 20 microseconds. So far only shock fronts in argon and nitrogen at low supersonic shock speeds have been measured by this method; for these gases it was found that the theoretical shock models were not greatly in error.

REFERENCES

[1] Lamb, H. 'Hydrodynamics' (6th ed.). Dover Publications Inc., New York. 1945.

[2] Rayleigh, Lord. *Proc. roy. Soc.*, A, **84**, 247, 1910.

[3] Courant, R. and Friedrichs, K. 'Supersonic Flow and Shock Waves'. Interscience Publishers Inc., New York and London. 1949.

[4] Mach, E. 'Popular Scientific Lectures'. The Open Court Publishing Company, Chicago. 1910.

[5] Black, J. *J.R. aero. Soc.*, **54**, 371, 1950.

[6] Pankhurst, R. and Holder, D. 'Wind Tunnel Technique'. Sir Isaac Pitman and Sons Limited, London. 1952.

[7] Holder, D. and North, R. *Nature, Lond.*, **169**, 466, 1952.

[8] Lighthill, M. *Proc. roy. Soc.*, A, **217**, 344, 1953.

[9] Taylor, G. I. *Ibid.*, **201**, 159, 1950.

[10] Lukasiewicz, J. National Aeronautical Establishment, Canada, Report 15, 192.

[11] Bleakney, W., White, D., and Griffith, W. *J. appl. Mech.*, **17**, 439, 1950.

[12] Resler, E., Lim, S., and Kantrowitz, A. *J. appl. Phys.*, **23**, 1081, 1952.

[13] Whipple, F. *Rev. mod. Phys.*, **15**, 246, 1943.

[14] Grad, H. *Commun. pure appl. Math.*, **5**, 257, 1952.

[15] Green, E., Cowan, G., and Hornig, D. *J. chem. Phys.*, **19**, 427, 1951.

The mycorrhiza of forest trees

J. L. HARLEY

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Although the fact that the roots of certain plants are commonly associated with fungi has long been known, the significance of this association has only comparatively recently become apparent. Experimental evidence indicates, however, that in the case of forest trees these root-fungal associations act as highly efficient aerobic accumulators of ions, assisting both plant and fungi in their competition for nutrients with other living organisms in the soil.

It has been known for more than a hundred years that many higher plants live in a close association with fungal mycelia which exist on or in the tissues of their roots. The activities of some of these fungi cause considerable changes in the morphology and anatomy of the roots, with the result that composite fungus-root structures, conspicuously different from uninfected roots, are formed. Changes resulting from the activities of other fungi may be externally invisible but nevertheless significant. The name mycorrhiza was first applied to fungus-roots of the first type by A. B. Frank [3], who made a detailed study of the roots of the European beech. He showed that similar mycorrhizas were present on the roots of many angiosperm trees belonging to the Cupuliferae and on the roots of the pines and related plants. Later the name mycorrhiza was extended to all those associations of fungi with the absorbing organs of green plants and of higher plant saprophytes, such as the colourless orchids, in which clear structural or histological changes result from fungal infection of normal healthy individuals in their natural habitats. At some stage in their life, or in some habitats, the majority of root systems and other underground absorbing organs of plants have now been shown to form mycorrhizal organs falling within the above definition.

Quite early in the study of mycorrhizas the opinion was formed that mycorrhizal infection in some way stimulated the growth of the plants which possessed them, and it was natural that the early hypotheses concerning their physiological functioning should associate them particularly with nitrogen absorption. The nitrogen-fixing role of the bacterial nodules on the roots of legumes had already been proved, and many agricultural experiments on the treatment of soils with manures had appeared to show that nitrogenous substances were of overwhelming importance in plant growth. The assumption, without rigorous experimental proof, of a stimulating effect of mycorrhizal infection, and its explanation in terms of nitrogen supply, combined with the lack of knowledge of the physiology of absorption of mineral substances by plant roots, has been in large measure responsible for the slowness with which an understanding of mycorrhizal phenomena has been reached. Another important factor which contributed to confusion of thought, was the tendency to assume that all kinds of fungus-root associations, which had been called mycorrhizas, were physiologically similar in spite of great structural diversity. To obviate this last difficulty only one type of mycorrhiza will be discussed in detail in this article; it should be realized that the results of the researches here described must not be applied to other kinds of mycorrhiza without very careful consideration of their own peculiar properties.

The ultimate rootlets of many of the trees most common in European and other temperate forests—such as beech, sweet chestnut, the birches, oaks, and hazel among the angiosperms, and the pines, spruces, and larches among the conifers—are all associated with fungi under natural woodland conditions. The structures of the mycorrhizas formed by them are very similar in all important respects. The rootlets, which are somewhat thick and blunt-ended, form closely aggregated racemose systems of branches, or more rarely, as in the pines, are repeatedly forked. Mycorrhizal roots of the beech growing in their natural surroundings are shown in figure 4 and their anatomical structure is illustrated in figure 5. The host tissue is completely surrounded by a tissue of fungal hyphae so closely knit into a false cellular structure, especially in the outer region, that interhyphal spaces are hardly discernible. The central core of host tissue is penetrated in its outer cortex by fungal hyphae which grow between the cells, within the thickness of the cell-walls, to form a network called, after the German plant pathologist who first described it, the Hartig net. Some hyphae penetrate into the lumina of the cells, but such penetration is variable in amount and may be almost completely absent. Hyphae in variable numbers also pass outwards from the fungal sheath into the soil. Some of the main branches of these root-systems, however, as well as some of the minor laterals, seem to remain uninfected for a great part of their life, and they show a more normal root structure, with root-caps and root hairs.

The detailed structural differences, and differences in histology and mode of growth, between infected and uninfected roots have been described in detail for some species, and a start has been made in explaining the differences in terms of auxin production by the fungi, but a discussion of this aspect of mycorrhizas cannot be attempted here. Many of the roots that long remain uninfected do become infected during some stage of their lives. Sometimes, as in the beech, they become overgrown by a complete fungal sheath which develops behind the rapidly growing apex of the root; during periods of stagnation in root growth in summer this sheath may actually close over the apex. In other cases, for instance in pine, an internal infection of the tissues follows differentiation of the cells behind the apex of the long roots.

The fungi concerned in the formation of tree mycorrhizas have been studied in detail by E. Melin [7, 8, 9, 10] and his associates in Sweden [11]. The most profitable method of identifying them has proved to be the culturing of mycelia from the commonest fruit bodies found in the vicinity of the host trees in their natural habitat, and testing of the ability of these to form mycorrhizas by inoculating them on to the roots of sterile seedlings. It has been demonstrated that a great number of toadstools belonging to the Agaricaceae and Boletaceae, and some puff balls, such as Scleroderma, form mycorrhizas. In all cases the physiological properties of the species are somewhat unusual. They show an inability to develop in culture on sources of carbon more complex than simple carbohydrates, and they frequently need supplies of accessory factors, such as the vitamins thiamin and biotin, for satisfactory development. They therefore contrast with other humus- and wood-inhabiting fungi of the same taxonomic groups which have powers of breaking down lignin and cellulose and which may be readily grown in culture. These cultural characteristics, together with a conspicuous lack of ability to compete in mixed culture with unspecialized soil saprophytes, link them physiologically more closely with specialized parasites than with litter- and humus-decaying forms. There is considerable evidence that many species are unable to produce fruit bodies in the absence of their host trees.

The intensity of mycorrhizal development upon any host plant varies with the conditions of its habitat. External factors seem to influence the development of mycorrhizal structures through their effects upon the host plant rather than directly upon the fungi. The earliest workers observed that the most intense development of infection occurred on humic soils where layers of partly decayed plant remains persisted as a permanent horizon on the soil surface. In this horizon an aggregation of mycorrhizal rootlets could be seen growing in close competition with large quantities of mycelia of very varied types. After periods of leaf fall there may be a temporary release of considerable quantities of plant nutrients into these humus horizons, but they are rapidly absorbed by the living components of the layer and the average content of available nutrients throughout the year is very low. In soils in which humus layers do not accumulate, and where the supply of available nutrients is permanently held at a higher level, mycorrhizal development is much less conspicuous.

The experimental results of A. B. Hatch [5] in America, later greatly extended by E. Björkman [1] in Sweden, have gone far to explain this variation. It appears that in any given light intensity in which growth is possible, mycorrhizal development increases with increasing deficit of plant nutrients, notably nitrogen and phosphorus and possibly also potassium. The higher the light intensity the higher is the content of available nutrients which will allow a given development of mycorrhiza. These relationships hold, of course, only within what may be called the working ranges of nutrient concentration and light intensity, and do not apply to conditions of acute starvation nor of great excess of nutrient, nor when the light is very intense, and they often require some modification to allow for the effects of interaction of the nutrients. The conclusion was therefore reached by Björkman, and confirmed by analysis, that infection depends upon the presence of excess carbohydrate in the root tissues. Since Björkman's important conclusion was published many other observations have been shown to agree well with his hypothesis. For example, the initial infection of seedlings after germination in both pines and beech does not occur until after the foliage leaves are expanded, when free carbohydrates are present in the root tissue. It is attractive, yet dangerous, to connect the demand for simple carbohydrates by the fungi in culture with these observations and to regard this as an instance of cause and effect. Other fungi, which are unable to form mycorrhiza, have similar demands for simple carbohydrates.

The relatively great development of mycorrhizas in soils deficient in nutrients led the earliest observers to a teleological interpretation of mycorrhizal function which survives till the present. Crudely stated, the argument was that the great development of mycorrhizal roots in soils low in nutrients proved that their function was to increase mineral absorption. Whatever the properties of mycorrhizal roots may be, this argument is quite valueless. Three kinds of ecological and experimental evidence are available respecting their functions as absorbing organs which are quite free from the taint of this error. First, attempts to establish trees, especially coniferous trees, in localities not natural to them have often failed, especially when plantings were done on humic soils; correlated with the failures were failures in mycorrhizal development. Various soil treatments, such as those performed by M. C. Rayner at Warham [12], have resulted in both a more satisfactory growth of the young plants and a development of mycorrhizas on their roots. To see these changes as examples of cause and effect would be rash without further evidence. Secondly, experimental inoculation of seedlings with mycorrhizal fungi, to compare their growth with that of uninoculated seedlings, has been attempted many times. Experiments of this kind, so simple in concept, are technically difficult to carry out, but the few fairly satisfactory ones show that on nutrient-deficient soils an increase in weight, coupled with a disproportionately large increase of nutrient absorption, occurs in the mycorrhizal seedlings. One example is given in table I, which summarizes results obtained by Hatch with *Pinus strobus*.

It has been assumed, following Hatch, that this increased mineral absorption in mycorrhizal seedlings results from the greater surface area in mycorrhizal root systems as compared with uninfected systems. The dangers in this suggestion lie first in the impossibility of finding a method whereby the root-surface areas can be compared with reasonable accuracy, and secondly in the implication that a root system surrounded by a fungal sheath has properties, in terms of absorption of minerals per unit area, similar to those of uninfected roots. Such a view was tenable only while nutrients were believed to enter by mass movement in the transpiration stream or by the physical process of diffusion. Now that salt absorption has been shown to depend on metabolic reactions, some modification of this hypothesis becomes necessary. From the very structure of mycorrhizal roots it follows that all materials that enter the host must pass in some way through the fungal tissue of the sheath, and that their mode of entry, as well as the form and quantity in which they enter, are likely to be different in infected and uninfected roots.

TABLE I

	Dry weight	*Nitrogen (% dry wt.)*	*Phosphate (% dry wt.)*	*Potassium (% dry wt.)*
Mycorrhizal seedlings	404·6	1·24	0·20	0·74
Non-mycorrhizal seedlings	320·7	0·85	0·08	0·43

Results of A. B. Hatch, 1937 [5].

In recent years experimental evidence of a third kind has been obtained by treating mycorrhizal roots as single functional organs rather than as a compound of two separate organisms lying side by side. The techniques used have often been exactly those used in the study of salt uptake by normal roots.

Melin and his associates [8, 9, 10] have elegantly demonstrated that the out-growing hyphae from the mycorrhizal sheath are capable of functioning analogously to root hairs. Pine seedlings were grown in sterile sand cultures in such a way that open culture dishes of mycorrhizal fungi could later be placed on the surface of the sand. In the course of time the hyphae from the cultures grew over the lips of their dish through the sand and formed mycorrhiza on the pine rootlets. By inserting isotopically labelled solutions of phosphate, nitrogen compounds, and metallic nutrients in the fungal cultures, the movement of these solutions to the roots and into the organs of the host plant could be followed.

Information concerning the rates of absorption, and the effect of external factors on these rates, has been gained using excised mycorrhizas of pine and beech in experiments of short duration. The rates of absorption by uninfected roots and infected roots, on an area or weight basis, have

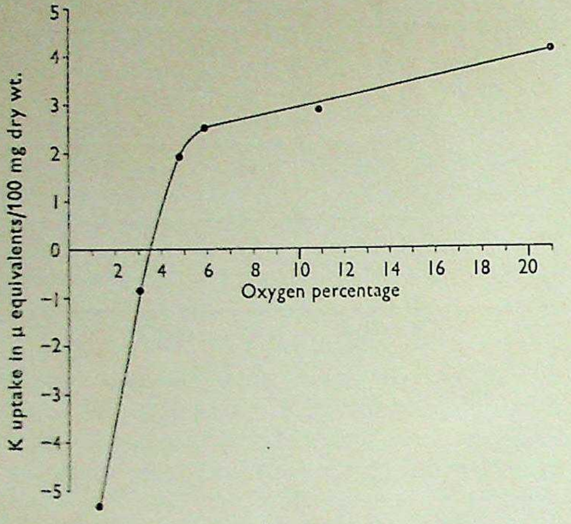

FIGURE 1 – *The effect of oxygen concentration upon the absorption of potassium from a solution of KCl* (0·128 *mM*) *during* 17 *hours by beech mycorrhizas.*

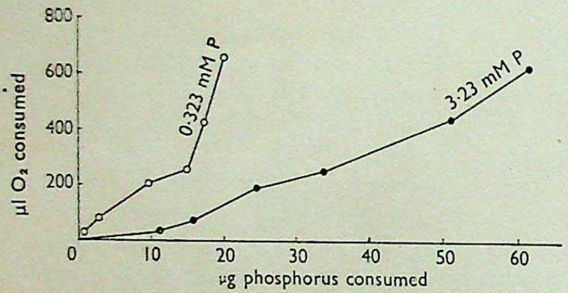

FIGURE 2 – *Relationship between oxygen consumed and phosphate absorbed, at two different concentrations, by beech roots.*

been compared in pine by P. J. Kramer and K. M. Wilbur [6] and in beech by J. L. Harley and his colleagues [4]. In each case a greater quantity was absorbed by infected roots; in the case of beech, for instance, phosphate was absorbed about five times, and potassium about twice, as rapidly. The rates of absorption by beech were particularly sensitive to oxygen supply, and the process of salt accumulation in the tissues is indirectly linked with respiration.

Figure 1 shows that potassium absorption occurs only at oxygen concentration above 3 per cent by volume, and reaches its maximum at between 10 and 20 per cent. Figure 2 shows the kind of relationship between oxygen consumption in respiration and phosphate absorption.

Mycorrhizal roots are similar to uninfected roots in the dependence of their absorption rate upon temperature, concentration of salt in the external solution, and the presence of substances inhibitory to metabolic processes. Both show the property of selective absorption, such as a preferential absorption of potassium from a mixed solution of alkali metals (table II).

TABLE II

Solution	*K uptake*		*Na uptake*	
	μE/ 100 *mg*	% *of Control*	μE/ 100 *mg*	% *of Control*
0·1 mM KCl	1·68	100	—	—
0·1 mM NaCl	—	—	0·41	100
0·1 mM NaCl + 0·1 mM KCl	1·37	82	0·06	14

Results of J. M. Wilson (unpublished).

This kind of result emphasizes the ability of mycorrhizas to accumulate salts as other absorbing organs do; although in some respects they differ greatly in experimental behaviour, their efficiency in salt accumulation cannot be doubted.

One important effect of the fungal sheath complicates this simple view of them as highly efficient salt-absorbing organs. A detailed examination of the immediate distribution of salts absorbed by mycorrhizal roots shows that the primary accumulation is not uniform, but that a large proportion of the salt absorbed is retained in the fungal sheath. This is particularly evident in phosphate absorption, where as much as 90 per cent of the absorbed ion is retained by the sheath in experiments of short duration, using the kinds of concentration likely to be present in soil solution. The release of accumulated phosphate to the whole system has been shown to be a gradual process, dependent upon temperature and oxygen supply (figure 3). It occurs only in oxygen concentrations

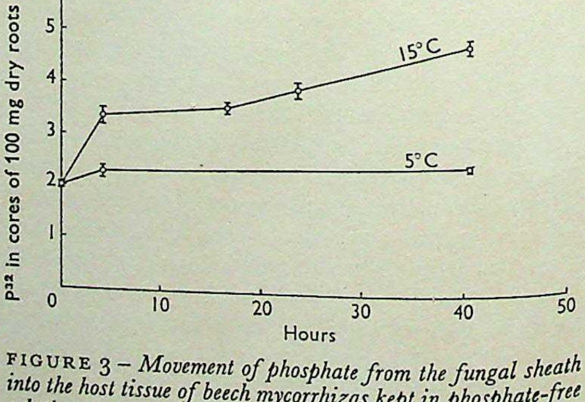

FIGURE 3 – *Movement of phosphate from the fungal sheath into the host tissue of beech mycorrhizas kept in phosphate-free solutions at* 5° C *and* 15° C.

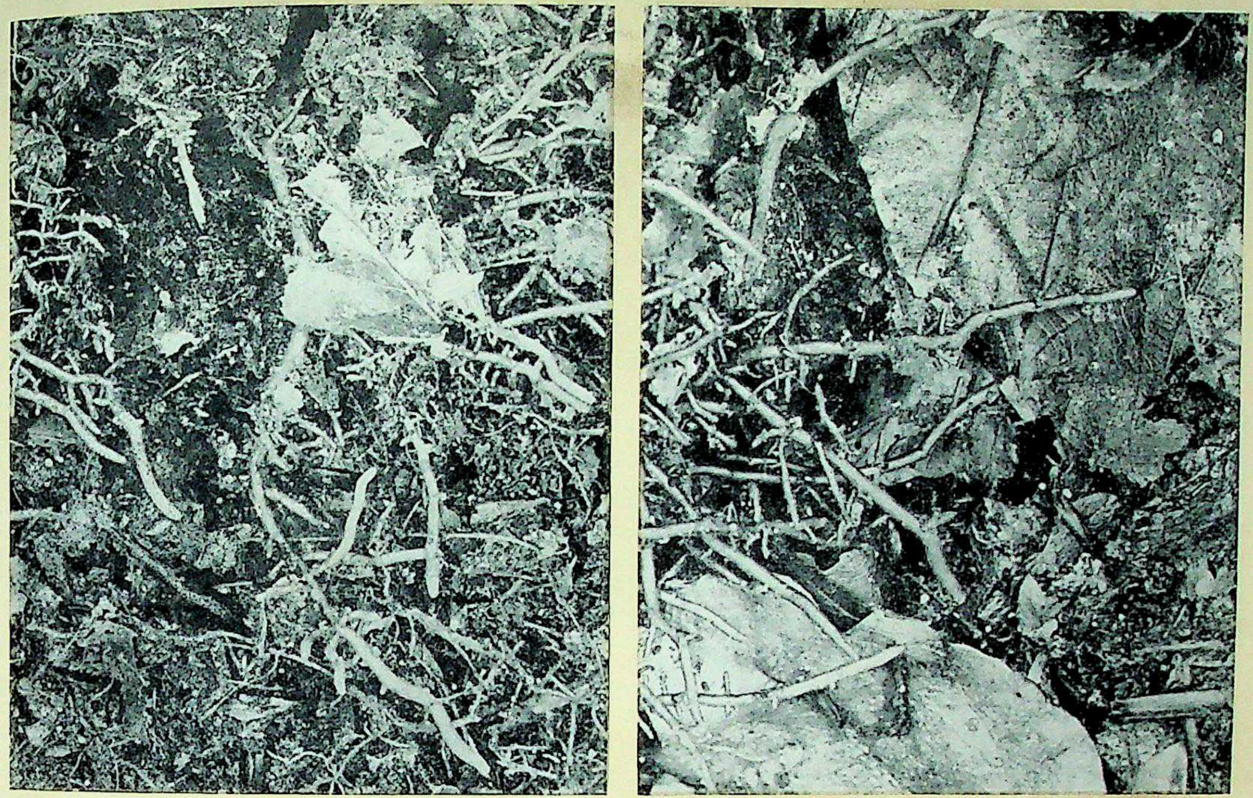

FIGURE 4 – *Photographs of mycorrhizal roots of beech in the humus layer of the soil.* (*Slightly enlarged.*)

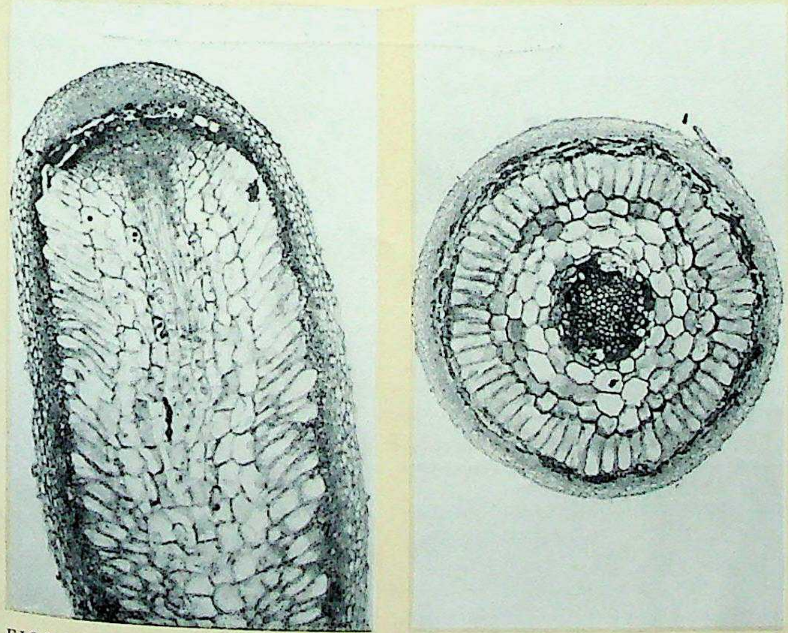

FIGURE 5 – *Sections of mycorrhizal roots of beech, showing the sheath of fungal tissue enclosing the host tissue. The hyphae of the Hartig net may be seen between the cells of the cortex.* (× 130 *approx.*)

(*Photograph by F. A. L. Clowes*)

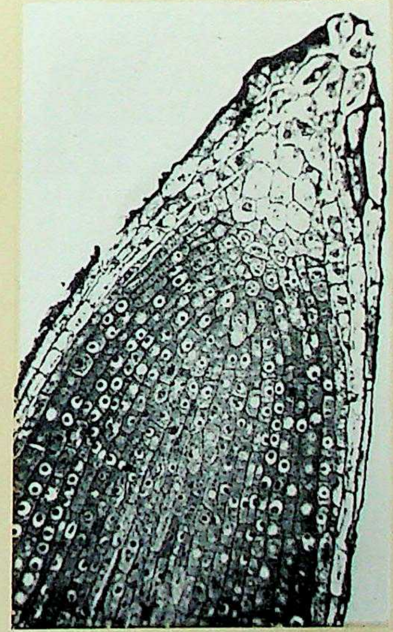

FIGURE 6 – *Longitudinal section of an uninfected beech root for comparison.* (× 200 *approx.*)

(*Photograph by F. A. L. Clowes*)

of above 3 per cent by volume, and it is most rapid in air when phosphate is absent from the external solution.

This experimental work on the rate of salt absorption has emphasized the aerobic nature of the processes of initial uptake and of redistribution. It has been explained that the uppermost humus layers of the forest floor are the natural site of the greatest development of mycorrhizas: consequently it is necessary to know the state of oxygen supply in these layers in order to apply the experimental results to natural conditions with any reliability. Estimates by J. K. Brierley [2] of the soil atmosphere in the zones of intense development of beech mycorrhiza have demonstrated no lack of oxygen. Throughout a whole season the oxygen concentration by volume remained above 19 per cent in all cases tested. One can therefore accept the view that mycorrhizal roots are highly efficient aerobic accumulators of ions, so that in times of litter breakdown they successfully compete for plant nutrients with other living organisms of the humus zones of forest soils. The material so accumulated may become available to both host and fungus by a gradual but metabolically dependent process of redistribution.

This recent experimental work has provided an adequate explanation of the many observations on the success of mycorrhizal plants in poor soil under both natural and experimental conditions, and has at last brought the study of mycorrhiza out of a phase where magical properties seemed to be ascribed to mycorrhizal organs. It is as absurd to assume that the development of mycorrhizas with the formation of the fungal sheath about the roots has no effect upon absorption as it is to suggest that forest tree seedlings cannot be grown without mycorrhizas. The seeds of forest trees will germinate and develop into seedlings in sand or water culture in conditions where no mycorrhizal organs are formed. Indeed, plants in heavily manured soils may grow exceedingly vigorously in a relatively uninfected state, but this is not their normal habitat nor their normal condition in their natural surroundings. Experiments in recent years, carried out under the aegis of the Forestry Commission, have aimed at determining whether it is necessary to raise nursery stocks of seedlings equipped with mycorrhizas for transplanting into forest soils, or whether seedlings heavily manured with inorganic fertilizers in their early life are successful as transplants, although initially non-mycorrhizal. Such results, when available, are likely to be highly important in shaping nursery policy, and they have already proved valuable in correcting far-fetched claims concerning the importance of mycorrhizas in development. The ecological and physiological experiments on mycorrhizas described in this paper are not concerned primarily, however, with these economic problems, but with the functioning of mycorrhizas as absorbing organs in forest conditions.

BIBLIOGRAPHY

[1] Björkman, E. *Symb. bot. upsaliens,* **6**, 2, 1942.

[2] Brierley, J. K. *J. Ecol.*, **43**, 404, 1955.

[3] Frank, A. B. *Ber. dtsch. bot. Ges.*, **3**, 128, 1885.

[4] Harley, J. L. and McCready, C. C. *New Phytol.*, **49**, 388, 1950; **51**, 56, 342, 1952; **53**, 92, 240, 1954.

[5] Hatch, A. B. *Black Rock For. Bull.*, No. 6, 1937.

[6] Kramer, P. J. and Wilbur, K. M. *Science*, **110**, 8, 1949.

[7] Melin, E. *Handb. biol. ArbMeth.*, **11**, 4, 1936.

[8] Melin, E. and Nilsson, W. *Physiol. Plant.*, **3**, 88, 1950.

[9] *Idem. Nature, Lond.*, **171**, 134, 1953.

[10] *Idem. Svensk bot. Tidskr.*, **49**, 119, 1955.

[11] Modess, O. *Symb. bot. upsaliens.*, **5**, 1, 1941.

[12] Rayner, M. C. and Neilson-Jones, W. 'Problems of Tree Nutrition.' Faber and Faber, London. 1944.

Book reviews

CYBERNETICS

The Human use of Human Beings (*revised edition*), *by Norbert Wiener. Pp.* 199. *Eyre and Spottiswoode (Publishers) Limited, London.* 1954. 18*s. net.*

This book was first published in 1950, and the present is a revised edition. Cybernetics is now defined as the science of messages, of their communication, and of the control which their communication can effect. Since society, apparently, is nothing at all but a form, or forms, of communication, it seems as if the science of messages ought to be able to explain all social phenomena. Professor Wiener believes that it can do this, but the fact is that the real interest of this book does not lie in his application of certain excessively generalized, familiar principles of cybernetics to social problems, but in his own brilliantly expressed and uninhibited reflections about many questions of contemporary interest. Among these are the processes by which human beings learn to know or to do things; the history, development, and use of language; legal problems in society, with special reference to views about punishment; and science and secrecy. Wiener displays an enormous fund of knowledge and an enviable certitude of expression. The critical reader may agree or disagree with some or all of what he says about these matters, and still legitimately remain convinced or unconvinced about the claims made for cybernetics as a social science.

F. C. BARTLETT

SCIENCE AND RELIGION

Science and Religion: A Changing Relationship, *by C. A. Coulson.* (The Rede Lecture for 1954.) *Pp.* 36. *Cambridge University Press, London.* 1955. 2*s.* 6*d. net.*

In this lecture Professor Coulson's aim is to describe the change in the relationship between science and religion which has been brought about by the progress of science. He deals with two aspects of this change, which he associates with nature and with man, but he points out that they overlap considerably.

Professor Coulson definitely rejects a modern tendency to divide nature into two parts in which science and religion have their respective fields of application, nor will he accept the view that God is to be found in the regions of thought into which science has not yet penetrated. Either God is in the whole of nature or He is not there at all; equally, the whole of nature is open to scientific treatment. The old objectivity of nature, however, is no longer tenable. It must be recognized that 'our intellect does not draw its laws from nature, but imposes its laws on nature'. In this respect the scientist is at one with the artist, the poet, and the saint; on the other hand, in the recent advances of science he is increasingly separated from them by the growing remoteness from ordinary experience of the most fundamental scientific conceptions.

Professor Coulson calls attention to man's displacement from the central position which he formerly occupied in the universe, to his insignificance in metrical terms, and to the fact that the nature in which he is involved is now without a centre for him to occupy—or, alternatively, every point in it is a centre. Such a universe can be regarded as 'somehow holding God', as a painting does, 'and God is, as it were, the canvas on which the painting depends'. But man, as well as being inseparably involved in this God-inhabited universe, is in another sense the author of it, since 'there is a definite sense in which nature itself . . . is a construct of man'. This complicated relationship between man and nature is quite different from the old view, in which man stood outside a completely objective nature and tried to describe it mathematically. The author concludes that with our greater knowledge, 'no satisfactory account of nature can be given except in personal terms'.

The lecture is very thought-provoking, and may be expected to meet with either approval or dissent according to the views of the reader. One effect of the changing relationship is that those who are willing to accord equal validity to science and religion will differ widely among themselves as to the point of view from which the whole subject can best be surveyed, and they will find each other's pronouncements not so much unacceptable as inapt. In these circumstances it is a salutary discipline to try to discover the angle from which the inaptness disappears. Professor Coulson's treatment lends itself readily to such an effort, and those who make it are likely to be well rewarded.

HERBERT DINGLE

STOCHASTIC PROCESSES

An Introduction to Stochastic Processes, *by M. S. Bartlett. Pp. xiv* + 312. *Cambridge University Press, London.* 1955. 35*s. net.*

Whenever a physical or biological system can usefully be thought of as developing in time under the influence of the laws of probability, the appropriate mathematical model of the system will be based on a stochastic process. The state of the system at the epoch t will then be represented by a random variable depending on t as parameter. Systems of random variables involving several parameters or a single parameter not identified with the time are also called stochastic processes and can be important (e.g. in the theory of turbulence) but the single (time-) parameter occurs in the great majority of applications. The theory of stochastic processes has developed with remarkable speed during the last ten years, outstanding contributions to its methodology having been made by Professor Bartlett and his school, first in Cambridge and now in Manchester. Nothing could be more timely than this most original book, addressed quite frankly to the 'practical' man who wants ideas he can develop rather than theorems he can quote (the theorems are to come later, in a companion volume by J. E. Moyal). Many readers of this book will be led to describe the phenomena in their own special field in a new and illuminating way. To others, and especially to those professionally concerned with the mathematics of Brownian motion, nearest-neighbour systems, queues, population growth, population genetics, epidemics and communication theory, the idea of a stochastic process will be already familiar, but the author's treatment of these problems will be worthy of their attention.

Of especial importance are the concluding chapters in which Professor Bartlett writes about the difficult problems of estimating the structural parameters in a stochastic model and testing the 'goodness' of the 'fit'. Here the classical statistical procedures are not available without modification, and a whole range of new problems of statistical inference present themselves.

D. G. KENDALL

ELEMENTARY MATHEMATICS

From Simple Numbers to the Calculus, *by Egmont Colerus. Pp. xi* + 255. *William Heinemann Limited, London.* 1955. 12*s.* 6*d. net.*

This is a translation from the original German, and it reads surprisingly well. It is in fact an admirable introduction to elementary algebra, trigonometry, and calculus. It is written in a most attractive style by one who has clearly given very much thought to the problem of expounding mathematics to his non-mathematical colleagues. Almost every difficulty is anticipated and dealt with adequately. The exposition is enlivened with a number of historical interludes and elucidated by means of numerous examples. The real attraction of the book is the way in which it proceeds from specific examples to general statements, and this enables the man or woman who is not a specialist in mathematics to gain some appreciation of its principles and methods.

G. TEMPLE

ASTRONOMY FOR AMATEURS

Amateur Astronomer's Handbook, *by J. B. Sidgwick. Pp.* 580. *Faber and Faber Limited, London.* 1955. 63*s. net.*

The many amateur astronomers who possess and use a telescope of their own will find this volume a storehouse of useful information on a great variety of subjects. It is not intended to be either a textbook or a practical manual of instructions. It is a reference volume which will assist the observer to use his telescope intelligently and efficiently, and to maintain it in good adjustment. The subjects dealt with include the light grasp, resolution, magnification, size of field, and aberrations of telescopes; types of oculars and objectives; optical materials and their properties; silver, aluminium, and other films on reflecting surfaces; types of telescopes, mountings, and drives; adjustments and testing; the atmosphere and 'seeing' conditions; micrometers, spectroscopes, and photometers; the eye and its role in observation; the use of photography and the properties of the photographic plate; diaphragms, filters, and clocks.

The book contains many useful practical hints, and the large number of line diagrams, which are of commendable clarity, add to its value. A bibliography of some 600 references provides a guide whereby the reader can obtain further information on most of the subjects discussed. The book, which is unique of its kind, will be invaluable to the practising observer. The printing and paper are of high quality.

H. SPENCER JONES

Observational Astronomy for Amateurs, *by J. B. Sidgwick. Pp.* 358. *Faber and Faber Limited, London.* 1955. 50*s. net.*

Designed to meet the needs of the amateur observer who possesses a small telescope and who wishes to use it for systematic observing, this book will meet a long-felt want. The fields in which the amateur observer can make the most useful contributions are observations of the Sun, Moon, planets, asteroids, comets, meteors, aurorae, zodiacal light, and variable stars. Methods and techniques of observations in all these fields are described, with many practical instructions and hints. The data tabulated in the Nautical Almanac and in the Handbook of the British Astronomical Association are explained, and at the end of each section the principal numerical data are listed. Methods of recording the observations are described. With this book as a guide the beginner will avoid many pitfalls and will soon gain the confidence and experience that are needed for enabling him to make contributions of value in the particular field of observation that he selects. A very comprehensive bibliography is given at the end, arranged according to the various sections, which will enable the observer to extend his knowledge of his chosen field of work.

In certain fields of observation astronomy must continue to depend considerably on the contributions of amateur observers. Careful study of this book by the amateur cannot fail to enhance the value of the observations that he makes.

H. SPENCER JONES

RADIO ASTRONOMY

Radio Astronomy, *by J. W. Pawsey and R. N. Bracewell. Pp. x* + 359. Clarendon Press, Oxford. 1955. 55*s. net.*

In the decade since the end of the last war, radio techniques have opened a new and exciting era in astronomy. The Radiophysics Laboratory of the C.S.I.R.O. in Sydney has played a leading role in these new advances, and in this book two distinguished members of its staff present a most valuable survey of the subject. Radio astronomy has grown up on the borderlines of astronomy, physics, and radio engineering, and any successful treatise on the subject must cater for a wide variety of interests. The authors have succeeded remarkably in their attempt to make this work intelligible to all concerned. It is, of course, inevitable that the writers' special interests and experience should receive most emphasis, and the third of the book devoted to solar radio emissions is outstanding in its thoroughness. At the same time it is somewhat disappointing to find that the account of galactic and extragalactic emissions is limited to a single chapter. The recent discoveries in this field of radio astronomy, including the spectral line from the neutral interstellar hydrogen gas, are of such significance that a more extensive treatment would have been justified. The study of thermal radio waves from the moon is covered in a short chapter, and the radio echo aspects of radio astronomy are very clearly dealt with in chapters on lunar echoes and meteors. The book will be indispensable to all workers and students in this subject, and no scientist reading this volume can fail to be excited by the remarkable developments of the last few years and the great potentialities for the future.

A. C. B. LOVELL

EARLY ELECTRICITY

The Development of the Concept of Electric Charge, *by Duane Roller and Duane H. D. Roller. Pp. iv* + 97. *Harvard University Press, Cambridge, Mass.* 1954. $1.60 *net.*

This little book is one of the Harvard 'Case Histories in Experimental Science', a series edited by Dr J. B. Conant. It traces the history of work on the electric charge from the earliest observations on frictional electricity down to the experiments of Coulomb, whose beautiful series of measurements with the torsion balance (incidentally, it was not he but Michell who invented the first such balance) established his famous law and so gave precision to the concept of electric charge.

This study, on a subject that has been comparatively little handled, gives much evidence of careful and sympathetic scrutiny of the records concerned, and the policy of providing extensive quotations, as well as diagrams, from the original books and memoirs is an excellent one. The description of Hauksbee, to whose work some prominence is justly given, as 'almost illiterate' seems unduly severe, and is not supported by the extracts furnished—would that some of the literates of today would describe their experiments as simply and clearly as he did his in his 'Physico-Mechanical Experiments'. This difference of opinion is, of course, a trifle, as are one or two other differences noted. The only serious fault that can be found in this commendable book is the frequent omission of precise references for passages quoted and experiments described, which is the more regrettable because it diminishes its usefulness for the student of the history of physics, who will be well advised to keep a copy on his shelves.

E. N. DA C. ANDRADE

QUANTUM ELECTRODYNAMICS

Einführung in die Quantenelektrodynamik, *by Walter Thirring. Pp. xii* + 122. *Franz Deuticke, Vienna.* 1955. *DM* 17.50 *net.*

This book grew out of a series of seminar lectures on quantum electrodynamics given five years ago. It is to be hoped that Dr Thirring's example of making his lecture notes available in published form may be followed by other specialists.

The title may prove somewhat misleading. The reader is expected to be already familiar with the original form of quantum field theory. He will find here, elegantly and clearly condensed, an account of both formal and conceptual developments during recent years. The emphasis, however, falls on formalism and applications, perhaps an advantage for anyone who, being already acquainted with the subject, may wish quickly to refresh his knowledge of technical points.

The book begins with a qualitative estimate of the orders of magnitude of the different physical effects which quantum electrodynamics is called upon to explain, and continues with a section on the classical theory of the electron. The quantum theory of fields is then founded on Schwinger's action principle. At this high level the interaction of the electromagnetic with the electron field is evolved as far as the discussion of divergences and renormalization. The electrodynamics of scalar particles is not treated, and references are somewhat scanty. A useful collection of problems and solutions is appended. E. CORINALDESI

ELECTRONIC THEORY OF VALENCY

An Introduction to the Electronic Theory of Valency (*third edition*), *by J. C. Speakman. Pp. vii* + 180. *Edward Arnold (Publishers) Limited, London.* 1955. 10*s.* 6*d. net.*

Those familiar with the earlier editions of Dr Speakman's lucid book on valency theory will welcome this new version, now made up to date and divided into two parts.

Part I describes, at sixth form or intermediate level, the rules, aptly called Sidgwickian, for writing simple electronic formulae. Only minor blemishes were noticed in a treatment admirably suited to its purpose: an impression that carbon monoxide is highly polar, and misleading values for the electron affinity of oxygen and the electrode potential of magnesium. The reader of Part II, assumed to be a first-year undergraduate, is introduced to most of the main ideas now current. A new chapter, excellent within the limits of pictorial description, discusses wave mechanics, including the valency bond and molecular orbital methods. Then follow such topics as bond lengths and energies, electronegativity, van der Waals' forces, the hydrogen bond, transition elements, acids and bases (including the Lewis concept), and non-stoicheiometric electron-deficient and clathrate compounds.

This rather unusual combination of text at two levels within a single volume should appeal particularly to the more adventurous sixth-former. One hopes, however, that the university freshman will also encounter a more rigorous treatment of some portion of this very wide field.

K. W. SYKES

ELEMENTARY CHEMISTRY

College Chemistry (*second edition*), *by Linus Pauling. Pp. xii* + 685. *W. H. Freeman and Company, California; Bailey Bros and Swinfen Limited, London.* 1955. 51*s. net.*

For the second edition of this book, which has had a considerable and well deserved success in the United States and is widely known in Britain, various changes in the sequence of the chapters have been made, and there is an entirely new chapter on the electron and the nuclei of atoms. Some new illustrative exercises are given in the text, and the exercises at the ends of the chapters have been considerably revised, with elimination of some of the more difficult ones. More attention is paid to organic chemistry, and there is a chapter on biochemistry. In general, the revision has been on lines intended not merely to bring the book up to date, but to introduce the facts, concepts, and theories of chemistry more gradually and more systematically than in the first edition.

For those not already familiar with the book, it may be said that it forms an excellent introduction to chemistry at first-year undergraduate stage and a most useful supplementary text for sixth-form science specialists. One has the impression that the student using it would realize that his steps were being guided by a master of his subject, and the confidence so inspired would lead to rapid progress. Besides the carefully chosen exercises there are at the end of each chapter two or three paragraphs summarizing the concepts and terms used in it, a feature enabling the reader to cross-examine himself on the extent to which he has assimilated what he has been reading. There are appendices on the metric system, physical and chemical constants, and the vapour pressure of water, together with a full index. The book is copiously illustrated with clear diagrams. As with so many American books, the price is high by British standards, but in this case the buyer would get full value for money. E. J. HOLMYARD

LAVOISIER

Lavoisier Théoricien et Expérimentateur, *by Maurice Daumas. Pp.* 180. *Presses Universitaires de France, Paris.* 1955. *Fcs* 700 *net.*

Dr Maurice Daumas, of the *Conservatoire National des Arts et Métiers*, Paris, is already well known for his valuable study, *Les Instruments Scientifiques aux XVII^{e} et XVIII^{e} Siècles*, a work which on its first appearance in 1953 was at once welcomed as a classic of its kind. His earlier book, *Lavoisier* (1941), written for the general reader, attracted much attention and has been republished in several editions. Here he turns again to Lavoisier with an authoritative, informed, and documented survey, presenting with masterly clarity in the brief space of 180 pages the work of the founder of modern chemistry as it unfolds in its eighteenth-century setting of ideas, methods, and apparatus. There can be no chemist who would not find this presentation of the historic foundation of his science of absorbing interest, especially as the author sets aside all questions of priority and, much more usefully, gives in one chapter a most valuable chronology of Lavoisier's researches and publications. A very interesting feature of the book is the chapter in which the author gives an account of his own long and careful researches on the composition of Lavoisier's classic *Traité élémentaire de Chimie.*

D. McKIE

CHEMICAL KINETICS

The Chemical Kinetics of Excited States, *by K. J. Laidler. Pp.* 180. *Clarendon Press, Oxford.* 1955. 30*s. net.*

Although in the majority of chemical reactions only the most stable electronic configurations of the participating species are involved, excited states play a crucial role in many processes, of considerable theoretical and practical interest, which occur in radiochemical or photochemical transformations and in flames. This book can be recommended to readers with some general knowledge of physical chemistry as an excellent survey of the fundamental concepts of a rather specialized branch of kinetics.

After a brief introduction on radiation and high-energy particles, the two main theoretical problems in the use of semi-empirical potential energy surfaces are discussed: the correlation of the various excited states of the transition complex with the appropriate levels of reactants and products, and the probability of transitions from one surface to another. Subsequent chapters deal with the various methods of excitation, and then with the elementary reactions of excited molecules such as dissociation, isomerization, association, and energy transfer. To illustrate the applications of these principles there are comparisons of the thermal, photochemical, and radiochemical mechanisms of some of the classical examples in chemical kinetics, e.g. ortho-para hydrogen conversion, decomposition of hydrogen iodide, combination of hydrogen and bromine. The book concludes with a chapter on the spectroscopic approach to flames.

K. W. SYKES

DYESTUFFS CHEMISTRY

The Chemistry of Synthetic Dyes and Pigments, *edited by H. A. Lubs. Pp. xii + 734. Reinhold Publishing Corporation, New York.* 1955. £7 8*s. net.*

The number of authoritative books on the chemistry or the manufacture of dyes and pigments is ridiculously small, and for this reason alone a new work of the scope and magnitude of this one will be welcomed. It is published as one of the American Chemical Society's well known monographs and maintains both in content and presentation the high standard of these publications. No single person can write with authority from first-hand experience of the many classes of dyes of which industry makes use, and this book is written by a team of nineteen contributors, all of whom, including the editor, have spent their scientific lives in the Jackson Laboratory of the Du Pont Company. The writers approach their subjects from the purely chemical aspect, discussing the processes involved in the preparation of intermediates and their conversion into dyes, and the properties of the dyes in relation to the functions they are expected to perform—the research workers' approach.

Although the fourteen chapters of the book cover all the different classes of organic dyes and pigments, the space devoted to each subject reflects the importance assigned to the different classes in America, as measured by dollar value of production. Most space is given to azo and azoic dyes (130 pages, four writers) and dyes derived from anthraquinone, including related vat dyes (216 pages, five writers); indigoid dyes are given 26 pages, sulphur dyes 33 pages, and a very large miscellaneous class which includes acridine, azine, thiazine, and the important triarylmethane dyes has to be content with 70 pages. However, the subjects in which the writers are obviously interested are admirably discussed. A feature of the book is the inclusion of a great deal of information gleaned from German sources after the last war and incorporated in FIAT and BIOS reports, information not well documented nor readily accessible. One must mention also the excellent account of the phthalocyanine pigments and dyes (no less than 50 pages). Full credit is given to British chemists for this discovery, certainly the most significant innovation in the field of synthetic dyes of the last twenty-five years.

E. H. RODD

THEORY OF INORGANIC ANALYSIS

Grundlagen der analytischen Chemie und der Chemie in wässrigen Systemen, *by F. Seel. Pp.* 348. *Verlag Chemie G.m.b.H., Weinheim/Bergstr.* 1955. *DM* 29 *net.*

In this book Professor Seel interprets to the first- or second-year student of inorganic analysis the theoretical background of aqueous-solution chemistry. The task is not an easy one, because it involves an introduction to selected physico-chemical problems at a stage where the student has not yet become acquainted with the basic principles of physical chemistry, but the author achieves his aim with some measure of success.

After deriving, perhaps somewhat naïvely, the mass-law on the concentration scale, by equating the forward and backward reactions on the basis of collision frequencies, the author introduces single-ion activities for the purpose of obtaining 'really constant' mass-law constants. Having thus avoided the complexities of thermodynamics, which might have frightened off the tender student, the author ably discusses the processes of solubility and precipitation, with the various implications deriving from crystal size and colloid formation. Equally well produced are the substantial chapters on the formation of complexes, on acid-base reactions, and on indicators. A small chapter (rather too small, considering the increasing importance of the subject in the analytical field) is devoted to ion exchange. The reader misses mention of 'mixed-bed' de-ionization, nor is there any reference to the analytically useful separations by ion exchange columns of mixtures such as Na-K, or to elution with complexing agents as in the case of Sr-Ba and rare-earth separations.

A substantial part of the book is devoted to the understanding of oxidation and reduction processes, reversible and otherwise, and the effect on them of complex formation. The various types of *p*H titration using indicators, redox potentials, and potentiometric cells get a fair discussion. Extensive tables are appended giving the *p*K values of solubilities and complex stabilities, as well as the normal redox potentials of a large number of compounds.

The treatment of the subject as a whole is obviously not intended for the more advanced analyst, and literature references, which might have filled the gaps unavoidable in a book of this size, are completely absent. But the book is well produced and, in spite of some limitations, contains a large number of valuable facts and data. It should make a useful contribution to the working knowledge of any young student of analytical chemistry, and should be extremely valuable to scientific assistants without a university training who work in analytical laboratories and who wish to understand the implications of what they are doing.

E. GLUECKAUF

PARASITISM

Some Physiological Aspects and Consequences of Parasitism, *edited by William H. Cole. Pp. xi + 90. Rutgers University Press, New Brunswick, New Jersey.* 1955. $2 *net.*

Since 1945 the Bureau of Biological Research at Rutgers University has sponsored annual conferences on some aspect of protein metabolism; in 1955 the conference took into account the important fact that parasitic organisms, even though they are not causing disease that produces clinical symptoms, may nevertheless alter the metabolic balance of the host, with the result that experimental animals considered to be normal are not, in fact, giving normal responses. The report of this conference shows that, although this problem is complex, valuable contributions have already been made to the study of it, and, indeed, to the study of the physiology of host-parasite relationships in general.

Studies of intracellular parasites are represented by William Trager's paper on the *in vitro* study of malarial parasites of birds; by Stauber's paper on leishmaniasis of the hamster; and by Moulder's discussion of the protein metabolism of bacteriophages, typhus rickettsiae, and malarial parasites. Taliaferro discusses his recent work on the formation of antisheep haemolysins in the rabbit; Bueding the glycolytic enzymes of *Schistosoma mansoni*; and Read intestinal physiology and its relation to the metabolism of tapeworms.

All these papers indicate that we stand on the threshold of research which will eventually transform our methods of dealing with parasites which still, in spite of recent remarkable advances in their control, cause heavy economic losses all over the world and incalculable human and animal suffering.

G. LAPAGE

GENETIC LETHAL FACTORS

Letalfaktoren, *by E. Hadorn. Pp.* 338. *Georg Thieme Verlag, Stuttgart.* 1955. *DM* 39 *net.*

This monograph is the first book devoted entirely to genetic lethal factors—that is to say, to genes which bring about the death of the individuals in which they are manifested. It is an important work, not so much because lethal genes differ in any profound way from others, but because they offer favourable technical opportunities for approaching two of the most fundamental topics in genetics—the nature of gene mutation and the manner in which genetic factors produce their developmental effects. Hadorn deals with both of these problems in some detail, although it is to the latter that the bulk of his book is devoted.

The particular merit of the book is its careful theoretical analysis, supported by the citation of many experimental and descriptive studies, of the complex syndromes of aberrations which a single gene may produce. Hadorn discusses in detail the evidence for the existence of particular phases of development at which the action of a given gene becomes manifest, and for cell and organ specificity in gene activity. His own recent work, in which he has used chromatographic methods to reveal the biochemical changes brought about by certain lethal genes, is fully summarized and its significance discussed. The book will be not only a most useful compendium and source of information, but by the clarity and comprehensiveness of its theoretical structure will contribute considerably to the advance of developmental genetics.

C. H. WADDINGTON

COOK'S VOYAGES

The Botany of Cook's Voyages (*Volume* 14, *Number* 5/6), *by E. D. Merrill. Pp. iv* + 161–384. *Chronica Botanica Company, Waltham, Mass.* 1954. $4.75 *net.*

The title of this work is somewhat misleading, since the author's interest is concentrated, not on the native vegetation of the areas visited during Cook's voyages, but only upon the introduced cultivated plants and weeds.

The material collected by Banks and Solander on Cook's first voyage (1768–71), and by the two Forsters on the second voyage, provide the main evidence for the views expressed by Dr Merrill. It is held that these collections were of a comprehensive character with respect to the areas visited, and demonstrate that most of the introduced plants of the Pacific islands today were arrivals subsequent to 1769. The Spaniards and Portuguese are considered to have been the pioneers in weed distribution throughout this area, and during the two hundred and fifty years of the Galleon Line from Mexico to the Philippines they probably introduced some two hundred species. The idea that American cultivated plants and weeds were widely dispersed in pre-Magellan times is discredited. Perhaps not more than two or three weeds of American origin became established on Pacific islands until within the last two centuries.

In 1769 two hundred and sixty plant species were collected in Tahiti, of which sixty-three were probably brought by human agency. Thirty of these have an economic value and may well represent deliberate introductions; there was a similar number of weeds, but of Indo-Malaysian origin.

The text of this work would have gained both in interest and effectiveness had the author been less polemical. It is obvious that his conclusions are based on considerable research, but though indexes are provided for both plant names and for authors there is no subject index, an omission that one regrets.

E. J. SALISBURY

PHOTOSYNTHESIS

Photosynthesis, *by R. Hill and C. P. Whittingham. Pp. vii* + 165. *Methuen and Company Limited, London.* 1955. 8*s.* 6*d. net.*

The study of photosynthesis has now progressed through stages based respectively on plant anatomy, plant physiology, physical chemistry, and biochemistry, and it is the special merit of this little book that, within its narrow compass, all these stages are fairly represented. It is interesting, for example, to find an adequate account of what may now be called the classical kinetic studies of the plant physiologists which provided basic data already rather apt to be overlooked.

The presentation is, in general, lucid, and will not overtax the abilities of the average degree student in botany or biochemistry; a few slips and ambiguities are noticeable mainly by contrast. There is some unevenness of treatment between different sections, presumably due to the dual authorship, and restricted space is doubtless the cause of some debatable statements being made *ex cathedra*. Chapter 6 contains a good deal of general biochemistry available elsewhere, and it might have been better to divert some of its pages to a description of supporting evidence, as is done in Chapter 7 but not much elsewhere.

The account of recent work is as up to date as can be expected, having regard to the delays of modern publication and the rapid progress of the subject. The authors are to be congratulated wholeheartedly on a remarkable achievement, and they have placed botany and biochemistry students heavily in their debt.

W. O. JAMES

POPULAR BOTANY

La Vie des Plantes, *by A. Guillaumin, F. Moreau, and C. Moreau. Pp.* 468. *Librairie Larousse, Paris.* 1955. *Fcs* 6190 *net.*

This is the latest addition to the *Collection inquarto Larousse* and is intended particularly as a companion volume to *La Vie des Animaux* published earlier. The aims of the series, in which this is the ninth title, are to provide an inspiring introduction to the world of ideas, irreproachable documentation of the sum of modern knowledge, illustration of a quality to charm the eye and enlighten the mind, and, generally, a presentation making full use of the progress of graphic art.

Having hitched the wagon to so high a star one can only fail honourably, if at all, and the three authors have indeed attacked their subject in the grand style. It would be difficult to think of any aspect of the plant sciences to which they have not alluded, from academic morphology to topiary, or from growing mushrooms in caves to growing millet on the equator.

The illustrations can be described only as magnificent, especially those in black and white, which are exciting even to a hardened botanist. This is the ideal present for an amateur of plants. Even if he were without the smattering of French necessary for reading the text, the 1518 illustrations would give him hours of enjoyment. There is unfortunately no index.

W. O. JAMES

RATS AND MICE

Les Rongeurs Domestiques Nuisibles, *by J. Lhoste. Pp.* 149. *Dunod, Paris.* 1955. *Fcs* 730 *net.*

In this recent addition to the series *Les Heures Scientifiques* Dr Lhoste provides a most useful, authoritative, and up to date handbook on rats and mice and their control. He begins by describing the chief differences between *Rattus norvegicus*, *Rattus rattus*, and *Mus musculus*, their parasites, and the diseases they spread. There follows a short section on proofing and rubbish disposal and then some eighty pages on methods of destruction—mainly chemical—wherein will be found the most interesting part of the book for readers already familiar with rodent control problems.

If this admirable publication can be criticized on general grounds it is because here and there, and perhaps to British eyes only, it lacks balance—as for example where it devotes nine pages to rubbish disposal in France, four pages to the botany of *Urginea maritima* and the extraction of red squill, and only eight lines to arsenic trioxide.

To mention specific points, surely more research needs yet to be done before the use of emetics in rat poisons can be recommended; and it is not generally true that warfarin is tasteless. There is a certain lack of correspondence between the text and figures 42 and 43; this is reduced, but not entirely eliminated, by transposing the latter. This tends to obscure the important fact stated only in the caption to figure 43, and at the very end of the book, that prebaiting is unnecessary with anticoagulants.

There is a short bibliography but no index.

E. W. BENTLEY

EMBRYOLOGY

Embryologie, *by D. Starck. Pp. xix* + 688. *Georg Thieme Verlag, Stuttgart.* 1955. *DM* 78 *net.*

Professor Dietrich Starck's new textbook of embryology is a notable addition to the literature. It is conceived in the form of an introduction to general problems leading to a very full account of the development of man. The latter, with its descriptions of placentation, organogeny, and histogenesis is treated in the light of comparative anatomy and gives a vivid presentation of normal and teratological development. The former section is remarkable for the breadth of its treatment. The classical information about the formation of germ-cells is accompanied by admirable sections on fertilization, gamones, the manifestation of the effects of genes in ontogeny, chromosomes, the determination of sex, and fundamental problems of the organization of the embryo by organizers and dependent differentiation. Beautifully produced and well illustrated, the book is thoroughly up to date and contains a mass of information which it would be difficult to find between two covers elsewhere.

The only criticism of the book which may be offered is that in some cases the references to literature in the text are not easy to pick out in the consolidated list at the end of the book, but this should not be held to detract from the welcome which its publication deserves. Its price is necessarily related to the substantial production which it represents, and is likely to prove beyond the reach of the ordinary student. The book should, however, be available in the libraries of all institutions where research and teaching on vertebrate embryology take place.

GAVIN DE BEER

BIRD NAVIGATION

Bird Navigation, *by G. V. T. Matthews. Pp. vii* + 141. *Cambridge University Press, London.* 1955. 12*s.* 6*d. net.*

Before the war, perhaps the biggest unsolved mystery connected with wild birds was how they found their way—their way home when experimentally released in unknown country and their way from breeding to winter quarters on their natural migrations. Since the war the problem has been largely solved, due especially to the work of G. Kramer at Wilhelmshaven and of the author of the present book while at Cambridge. The spur to the new approach was Kramer's brilliant observation that a caged starling, exhibiting migratory restlessness, tended to fly in one direction, and experiments showed that it found this direction by means of the sun's position and some form of internal clock. Later have come many carefully conducted experiments on the homing of pigeons by Kramer and Matthews. Matthews also obtained valuable, and at times spectacular, results with Manx shearwaters, one of which homed from the United States to Wales.

The present book is a well ordered and competent review of existing knowledge. It is based on the author's own research, together with many judicious and critical references to the work of others, and he presents a well reasoned and modestly argued case for his own theory of bird navigation by means of a grid derived from the sun's arc.

Perhaps because this mystery has in the past evoked so much highly coloured writing from the nature journalist, the author has written throughout in the dry technical language of the laboratory; this is a pity, because, with greater simplicity in the telling, the tale would have fascinated many amateur bird-watchers.

DAVID LACK

PHYSIOLOGY OF DIAPAUSE

The Physiology of Diapause in Arthropods, *by A. D. Lees. Pp. x* + 151. *Cambridge University Press, London.* 1955. 12*s.* 6*d. net.*

The phenomenon of diapause, or arrested growth, has been for many years of great concern to physiologists and economic entomologists, and Dr A. D. Lees' summary and reassessment of literature on this subject is timely and welcome. There is a growing interest in this general biological problem, and more than half of the 286 papers cited have been published within the last decade.

The author points out that the term diapause is a reminder of the physiological mechanisms which are absent in the state of quiescence and assembles much recent information on the metabolic and biochemical adjustments of dormant insects and mites. Much of the book is devoted to the influence of the environment on diapause, and the section on the effect of the length of day on dormancy is particularly stimulating.

One of the most outstanding advances in the study of diapause is the discovery that it is controlled by hormones and that different endocrine systems are concerned in the embryonic, larval-pupal, and the imaginal diapause. The recent discovery that a hibernating hormone affects the rate of embryonic development, as well as the extensive work on the endocrinology of diapause of larvae and pupae, are admirably summarized. The unifying principles underlying the phenomenon of diapause are only now beginning to emerge, and the author is not to be blamed if at times the ideas expressed in this monograph are not as clearly defined as one would wish.

It seems almost ungracious to point out minor mistakes in a monograph produced at such a high standard, but it is perhaps worth noting the race of *cinerescens* of *Lucasta migratoria* is wrongly referred to as *canescens*.

N. WALOFF

Some books received

(*Note.* Mention of a book on this page does not preclude subsequent review.)

ASTRONOMY

The Sun and its Influence, *by M. A. Ellison. Pp. xii + 235. Routledge and Kegan Paul Limited, London.* 1955. 21*s. net.*

BIOLOGY

Fibrous Proteins and their Biological Significance (Symposium of the Society for Experimental Biology, No. 9). *Pp. vi +* 370. *Cambridge University Press, London.* 1955. 50*s. net.*

The Luminescence of Biological Systems, *edited by F. H. Johnson. Pp. xiv +* 452. *American Association for the Advancement of Science, Washington, D.C.* 1955. $7.

The Mechanism of Evolution, *by W. H. Dowdeswell. Pp. ix +* 99. *William Heinemann Limited, London.* 1955. 6*s. net.*

Problèmes de structures, d'ultrastructures et de fonctions cellulaires, *edited by J. A. Thomas. Pp.* 358. *Masson et Cie., Paris.* 1955. *Fcs* 3000 *net.*

Receptors and Sensory Perception, *by R. Granit. Pp. xi +* 369. *Yale University Press, Newhaven; Geoffrey Cumberlege, Oxford University Press, London.* 1955. 40*s. net.*

BOTANY

Contributions to Plant Anatomy, *by I. W. Bailey. Pp. xxvi +* 285. *Chronica Botanica Company, Waltham, Mass.* 1955. $7.50 *net.*

Handbuch der Pflanzenzüchtung (*second edition*), Volume 1, *edited by H. Kappert and W. Rudorf. Pp.* 80. *Verlag Paul Parey, Berlin.* 1955. *DM* 13.50 *net.*

CHEMISTRY

Biochemistry of Autotrophic Bacteria, *by H. Lees. Pp. viii +* 112. *Butterworths Scientific Publications, London.* 1955. 21*s. net.*

The Chemistry of Petroleum Hydrocarbons, *edited by B. T. Brooks, C. E. Boord, S. S. Kurtz, and L. Schmerling.* Volume 2, *pp. vi +* 448; Volume 3, *pp. vii +* 690. *Reinhold Publishing Corporation, New York; Chapman and Hall Limited, London.* 1955. 108*s. net and* 144*s. net respectively.*

Physical Chemistry, *by F. Daniels and R. A. Alberty. Pp. vi +* 671. *John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1955. 52*s. net.*

The Quantitative Analysis of Drugs (*second edition*), *by D. C. Garratt. Pp. xv +* 670. *Chapman and Hall Limited, London.* 1955. 70*s. net.*

GENERAL

Directory of Scientific Research Organizations in the Union of South Africa, *edited by D. Ryle Masson. Pp. ix +* 123. *J. L. Van Schaik Limited, Pretoria.* 1955. 25*s. net.*

The Foreseeable Future, *by Sir George Thomson. Pp. vii +* 166. *Cambridge University Press, London.* 1955. 10*s.* 6*d. net.*

Machine Translation of Languages, *edited by W. N. Locke and A. D. Booth. Pp. xii +* 243. *The Technology Press of The Massachusetts Institute of Technology and John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1955. 48*s. net.*

The Practice of Management *by P. F. Drucker. Pp. viii +* 355. *William Heinemann Limited, London.* 1955. 25*s. net.*

Proceedings of the Commonwealth Oceanographic Conference, 1954. *Pp. v +* 92. *Cambridge University Press, London.* 1955. 7*s. net.*

Two Ears of Corn, Two Blades of Grass, *by D. H. Killeffer. Pp. x +* 139. *D. Van Nostrand Company Inc., New York; Macmillan and Company Limited, London.* 1955. 30*s. net.*

MEDICINE

Advances in Experimental Caries Research. *Pp. ix +* 236. *American Association for the Advancement of Science, Washington, D.C.* 1955. $6.75.

Antimetabolites and Cancer, *edited by C. P. Rhoads. Pp. vi +* 312. *American Association for the Advancement of Science, Washington, D.C.* 1955. $5.75.

British Medical Bulletin, Volume 11, No. 2 (Hormones in Reproduction), *edited by A. S. Parkes. Pp.* 83–170. *The British Council, London.* 1955. 15*s. net.*

British Pharmacopoeia 1953. Addendum 1955. *Pp. xvii +* 94. *The Pharmaceutical Press, London.* 1955. 21*s. net.*

Experimental Tuberculosis, *edited by G. E. W. Wolstenholme. Pp. xii +* 396. *Ciba Foundation Symposium. J. and A. Churchill Limited, London.* 1955. 42*s. net.*

The Extra Pharmacopoeia (Martindale), Volume 2 (*twenty-third edition*). *Pp. xxxi +* 1501. *The Pharmaceutical Press, London.* 1955. 57*s.* 6*d. net.*

Symposium on Atherosclerosis. *Pp.* 249. *National Academy of Sciences—National Research Council, Washington, D.C.* 1954. $2 *net.*

PHYSICS

Boltzmann's Distribution Law, *by E. A. Guggenheim. Pp.* 61. *North-Holland Publishing Company, Amsterdam.* 1955. 5*s.* 6*d. net.*

Journal of Electronics, Volume 1, No. 1. *Pp.* 102. *Taylor and Francis Limited, London.* 1955. 20*s. net.*

Molecular Beams, *by K. F. Smith. Pp. x +* 133. *John Wiley and Sons Inc., New York; Methuen and Company Limited, London.* 1955. 8*s.* 6*d. net.*

Nuclear Radiation Detectors, *by J. Sharpe. Pp.* 179. *Methuen and Company Limited, London.* 1955. 11*s.* 6*d.* net.

Optique électroniques, Volume 1. Lentilles électroniques, *by P. Grivet, M.-Y. Bernard, and A. Septier, with a preface by Louis de Broglie. Pp.* 84. *Bordas, Paris.* 1955. *Fcs* 1450 *net.*

Principles and Applications of Physics, *by O. Blüh and J. D. Elder. Pp. xiv +* 866. *Oliver and Boyd Limited, London.* 1955. 45*s. net.*

Radiocarbon Dating (*second edition*), *by W. F. Libby. Pp. ix +* 175. *The University of Chicago Press, Chicago; Cambridge University Press, London.* 1955. 34*s. net.*

ZOOLOGY

Biology of a Marine Copepod, *by S. M. Marshall and A. P. Orr. Pp. vii +* 188. *Oliver and Boyd Limited, London.* 1955. 21*s. net.*

Birds of Saurashtra, India, *by R. S. Dharmakumarsinhji. Pp. liii +* 561. *R. S. Dharmakumarsinhji, Dil Bahar, Bhavnagar, Saurashtra.* 1955. £5 12*s.* 6*d. net.*

A Catalogue and Historical Account of the Banks Shell Collection, *by G. L. Wilkins. Pp.* 69–119. *British Museum (Natural History), London.* 1955. 20*s. net.*

Notes on contributors

J. Z. YOUNG,
M.A., F.R.S.,

Was born in 1907 and was educated at Marlborough College and the University of Oxford. Specializing in zoology, he worked for two years at the Marine Biological Station at Naples, afterwards returning to Oxford, where he became Fellow of Magdalen College and University Demonstrator in Zoology. He is now Professor of Anatomy at University College, London. His research work has been on the microscopic structure and function of various tissues, especially in the nervous system. During 1936 he held a Fellowship of the Rockefeller Foundation and worked at Chicago and Woods Hole, Mass. Before the war while investigating the nervous system of squids he discovered the giant nerve fibres which have proved exceptionally suitable for experiment. During the war he conducted research on methods of treating injuries of peripheral nerves and was a member of the Nerves Injuries Committee of the Medical Research Council. Since the war he has done much work on octopuses and similar animals in an attempt to throw light on the mechanism of learning.

H. M. POWELL,
M.A., B.Sc., F.R.S.,

Was born in 1906 and was educated at King Henry VIII School, Coventry, and St. John's College, Oxford. In 1929 he was appointed Demonstrator in the former Department of Mineralogy and Crystallography, Oxford, where he began to apply X-ray crystal analysis to chemical problems. In 1944 he was appointed Reader in Chemical Crystallography, in charge of a reorganized department devoted to that subject. His crystal structure investigations deal with molecular compounds, stereochemical types, and the constitutions of organometallic compounds, phosphorus pentahalides, metal carbonyls, and ferrocyanides. His most recent investigations have been on stable molecular compounds formed by the inert gases.

H. J. J. WINTER,
D.Sc., Ph.D., A.Inst.P.,
F.R. Asiatic S.,

Was born in 1912 and was educated at the City School, Lincoln, University College, Nottingham, and University College, Exeter. He is a member of the History of Science Society and of the British Society for the History of Science. Lecturer in Education (Scientific Method and History of Science) in the University College of the South West, Exeter. He has published 'Eastern Science' and many papers on the history of science.

A. W. JOHNSON,
M.A., Ph.D., A.R.C.S.,

Was born in 1917 in South Shields, County Durham, and was educated at Morpeth Grammar School and, after two years in industry, at the Royal College of Science, South Kensington. After carrying out research on the synthesis of vitamin A with Sir Ian Heilbron, he took up in 1942 a research appointment with I.C.I. Dyestuffs Division, working on the chemistry of acetylene and its derivatives. In 1946 he was awarded an I.C.I. Fellowship at the University of Cambridge in Professor Sir Alexander Todd's department. In 1948 he was made Assistant Director of Research and, in 1953, University Lecturer in Organic Chemistry. His research has covered a variety of natural products, including vitamin B_{12}. In 1955 was appointed Sir Jesse Boot Professor of Organic Chemistry in the University of Nottingham. Was awarded the Meldola Medal of the Royal Institute of Chemistry in 1946, and gave the Tilden lecture of The Chemical Society in 1953.

SIR ALEXANDER TODD,
M.A., D.Sc., Hon. LL.D., Hon. Dr. Rer. nat., F.R.S.,

Was born in Glasgow in 1907 and was educated at Allan Glen's School and the University of Glasgow. He continued his studies at the Universities of Frankfurt and Oxford, and in 1935–36 was Beit Memorial Research Fellow at the University of Edinburgh. After holding posts at the Lister Institute, London, the University of London, and the California Institute of Technology, he was appointed Professor of Chemistry and Director of Chemical Laboratories in the University of Manchester in 1938. Since 1944 he has been Professor of Organic Chemistry in the University of Cambridge. He is a Davy Medallist (1949) and Royal Medallist (1955) of the Royal Society, and since 1952 has been chairman of the Advisory Council on Scientific Policy. He has always been keenly interested in the biological side of organic chemistry, to which he has made numerous and important original contributions.

E. W. E. ROGERS,
M.Sc., D.I.C., A.F.R.Ae.S.,

Was born in London in 1925 and educated at Southgate County School and Imperial College, London. In 1945, after a year's post-graduate work in aeronautics, he joined the High Speed Group of the Aerodynamics Division at the National Physical Laboratory, where he has since been engaged in research on air flows at subsonic and supersonic speeds. He is the author of several papers on high-speed aerodynamics, and is a member of the secretariat of the Aeronautical Research Council.

J. L. HARLEY,
M.A., D.Phil.,

Was born in 1911 and was educated at Leeds Grammar School and Wadham College, Oxford. Is now University Demonstrator in Botany at Oxford and Fellow of The Queen's College. His research has been mainly in the fields of mycology and ecology, and he has published papers on mycorrhiza, the ecology of fungi, and root-surface population of micro-organisms.

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Editor: TREVOR I. WILLIAMS, M.A., B.Sc., D.Phil., F.R.I.C.
Foreign Editor: J. A. WILCKEN, B.Sc., Ph.D.

Imperial Chemical Industries Limited, Millbank, London, S.W.1
Communications to the Editors should be addressed to North Block, Thames House, Millbank, London, S.W.1

Some limits to popular science

Travellers in foreign countries seem sometimes to believe that they will be perfectly understood if they speak loudly and clearly enough in their own language. Such a fancy is harmless enough, but it rightly makes ridiculous those who display it. Yet there seems to be growing up a similar belief which is scarcely less ridiculous but not entirely harmless—a belief that all the mysteries of science can be made clear to the layman if only scientists will take the trouble to explain themselves in very simple terms. In the circumstances of today it is undeniably desirable that the general public should have an appreciation of science in the widest sense—its discipline and its methods, its results and applications, its promises and its dangers, its organization and its practitioners. This aim is laudable, but no useful purpose is served by propagating the belief that there are no limits to the success which may be achieved.

Clarity of exposition is certainly of the greatest possible assistance here, as in the communication of any other kind of knowledge, and it is undoubtedly true that scientists have much to learn not only in explaining themselves to the layman but in explaining themselves to each other. Nevertheless, there are limits to what the most lucid thinker and writer can do when seeking to enlighten untrained and often unreceptive minds. This is true of all complex human activities, and it is curious that while it is so generally recognized in many other spheres it is so often ignored in discussing the popular exposition of science. An analogy can perhaps fairly be drawn from the ancient and widely played game of chess. All the world may appreciate that it is skill and patience which lead to victory or rejoice in the success of their local or national champion. But no one would suggest that the spirit of the game, the danger of a particular situation, the precise point at which the play turns in favour of one player or the other, and all the fine points mastered only after years of play, can be appreciated by those who do not know even the basic moves assigned to the pieces. This fact is accepted by those seriously minded newspapers which regularly have columns on chess—such columns are always written in a style designed to convey as much information as possible to the enthusiast, but make no pretence of catering for the uninitiated. This does not, of course, mean that nothing interesting can be said about chess in more popular publications. There, however, the emphasis must rightly be placed upon those limited parts of the subject which a wider readership will find interesting and intelligible. The result itself, the idiosyncrasies of the players, unusually brief or protracted play, can all be touched upon. But none would suppose that this kind of comment tells us wherein lies the absorbing interest of the game for those who play it or anything of the complex tactics which determine success.

The analogies can be multiplied almost endlessly. Can the tone-deaf appreciate a fine orchestral performance, or any but a trained jurist appreciate the subtle points of a complex legal argument? Again, however, there are parts of such matters which anybody with an inquiring mind can grasp even in the short time it is possible for the ordinary person to devote to the pursuit of, to him, relatively minor interests. Similar arguments can surely be applied to the popular exposition of science. Parts of the subject must surely remain a closed book to the layman virtually by definition; when he can read these pages he is no longer a layman but entitled to call himself a scientist, whether he reaches this status by institutional or private study. This is a fact implicitly recognized by all the most successful writers of science for laymen: their genius has been not in explaining science as a whole, but in explaining those parts of it which can be made intelligible and interesting to the ordinary person with very limited time to spare.

Generally speaking, unfamiliar matters, whether scientific or otherwise, can be understood so far as the reader can relate them to his own general knowledge and experience. He can appreciate the general nature of many major scientific discoveries, and he can understand their likely effect on his daily life if they were to be widely applied. That he ought to have this kind of knowledge is generally agreed. A high rate of technical development seems, whether we like it or not, to be the only answer to the acute problem presented by a world population that is both increasing rapidly and clamouring for a higher standard of living. To achieve this development, the widest and speediest possible dissemination of technical knowledge is essential, since the necessary decisions on policy are still largely in the hands of non-scientists.

Even on the purely factual side of science, however, there are many important discoveries which it is virtually impossible to explain to the layman in anything but the most superficial way, for they are too remote from his experience and ordinary modes of thought. It is, for example, surely no accident that while the major applications of chemistry are quite widely known, for they form part of our daily lives, the whole realm of theoretical chemistry has been virtually untouched by the popular expositor. The elegance of an ingenious organic synthesis or the nature of the dynamics of a complex reaction cannot be conveyed to those with no prior knowledge. The public, for example, may accept the fact that the elucidation of the structure of vitamin B_{12} is a great achievement, but they cannot be expected to see wherein its greatness truly lies.

There are other barriers to popular understanding. Science would be an uninspiring business if it consisted of no more than the collection of new facts and their application for practical ends. These are but the beginning and the rounding off of a complex process. To be manageable, facts have to be marshalled within the limits of general laws, from which in turn new facts may be deduced. Practical applications almost invariably call for the solution of problems scarcely less difficult—and, indeed, often more difficult—than those involved in the original discovery. Many non-material factors also are involved: imagination to see the significance of facts, pleasure from the pursuit of knowledge for its own sake, the satisfaction of the creative impulse. It is surely unduly optimistic to hope that mere clarity of writing will suffice to convey to the layman a proper understanding of the whole complex intermingling of the material and the abstract which constitutes modern science. How long is it seriously supposed he can give to reading about this vast subject? Surely it is at the very best no more than will enable him to scratch at the surface, for even the individual scientist can today apply himself to only a very small part of it.

In talking of the popular exposition of science it thus seems easy to confuse the part with the whole, to suppose that the present vast outpouring of popular scientific material represents all aspects of scientific activity. The point is not merely of academic interest; it is of considerable practical importance also. For better or for worse, scientists have a great, and still rapidly increasing, influence on world affairs; one can see no limit to the material achievements of science. Not surprisingly, there are grave misgivings about this, for it is only too apparent that evil as well as good can spring from scientific progress. That the great majority of scientists are interested in applying their work only to beneficial ends may be well known in scientific circles, but it would be complacent to suppose that all the world is convinced of this. Nothing could be more damaging to good relations between scientists and the public than a suspicion that they are deliberately hiding knowledge of their activities by describing them in language so esoteric and obscure as to be incomprehensible to any but their fellow experts. It would be far more useful, and less productive of disillusionment, to teach that science is in reality a strict discipline demanding patient application. If he really wants to understand science, and not merely its more obvious results and applications, the layman must be prepared to study it seriously. How this is to be achieved, however, in an age in which there are so many interests to occupy hours of leisure, entails argument far too controversial and complex to be embarked upon here. It does seem, however, that the time has come for more general introduction of science into primary education.

In the years to come, the world will inevitably turn more and more to science to solve the grave practical problems which beset it. The response will certainly be wholehearted, but one would have to be very optimistic to believe that there will be no disappointments. These will be all the greater if it is believed that science is really a relatively simple matter, for it could make failure seem the result of indifference or preoccupation with more sinister research, rather than of the intrinsic difficulty of the problems themselves. A limit to the extent to which science can help the world is set by the number of people who are able and willing to give the time and trouble necessary to acquire scientific knowledge appropriate to their purposes. This applies, of course, not merely to science but to all learning: superficial knowledge will never be an effective substitute for real understanding. It is rather easy to forget that it is not on science but on scientists that we depend for the solution of some of our pressing problems.

Quantum mechanics and common sense

ALFRED LANDÉ

The belief has grown up in recent years that quantum rules are so fundamental that they must be looked upon as axiomatic and incapable of explanation in general terms. The present article argues that this defeatist attitude is unnecessary and that an understanding of quantum mechanical axioms can in fact be gained from a logical approach to the subject, based on the fundamental assumption of continuity of cause and effect.

Quantum mechanics has the reputation of being incomprehensible to all but a select group of theoretical physicists schooled in complex mathematical techniques and trained in the art of abstract reasoning. This reputation is enhanced by a strange dualism between corpuscular and wave-like manifestations of matter, by an uncertainty replacing the determinacy of causal chains, and by a complementarity preventing us from forming any definite image of the microphysical world and asking us instead to be satisfied with a mathematical formalism capable of embracing a variety of phenomena of an apparently contradictory character. When penetrating further into the sanctuary of quantum theory we are confronted with revolutionary hypotheses, today hardened into axioms, such as the Planck oscillator rule, $E = h\nu$, or the modern quantum prescriptions of Schrödinger and Born-Heisenberg 'involving strange ideas and some processes of calculation which cannot in detail be understood' (J. Lennard-Jones [2]). The novice is supposed to accept the quantum rules at face value 'because they work'; later on, when he has practised them for years, he may even become oblivious of their problematic character. Or, if he preserves his open mind, he may agree with P. W. Bridgman [1] that 'when we go far enough in the direction of the very small, quantum theory says that our forms of thought fail, so that it is questionable whether we can properly think at all . . . Eventually we shall have to find better ways of thinking.' This is a rather distressing state of affairs after twenty-five years of duality, uncertainty, and complementarity. Shall we accept for ever an array of unintelligible formalistic rules which happen to work, or will it be possible to conceive quantum theory as a manifestation of simple physical principles?

A hopeful note to this effect has been struck by Bridgman in the article already cited [1]:

> 'I believe the experts would at present agree that whatever new way we devise to think about the microscopic universe, the meaning of our new concepts will have to be found back at the level of the large-scale events of daily life, because this is the scale on which we live our lives, and it is we who are formulating the new concepts. This recognition and agreement entails, I believe, a consequence that is not commonly appreciated, namely, that the seeds and sources of the ineptness of our thinking in the microscopic range are already contained in our present thinking in the large-scale region and should have been capable of discovery by sufficiently acute analysis of our ordinary common-sense thinking.'

These are prophetic words indeed; and the prophecy has to a certain extent come true, as the present article intends to show. An understanding of the enigmas, now dogmas, of quantum mechanics can indeed be gained through a common-sense approach, and could have been gained ever since Schrödinger, Born, and Heisenberg succeeded in merging the incoherent quantum rules of the older theory into a consistent structure. But the road to a common understanding has been obstructed by the historical development, which derived its impetus more from spectacular discrepancies between microphysical observation and classical expectation than from a critical analysis of the intrinsic failings of the classical theory itself. With the sole exception of the Bohr correspondence principle, the emphasis was always on the dramatic and revolutionary, and it had to be so in order to justify the break with the Newtonian tradition. Then at last it all seemed to condense in the Schrödinger equation, today placed at the entrance gate to quantum theory. But this is like beginning a study of electromagnetism with the Maxwell-Lorentz field equations rather than with moving magnets and coils of wire, or mechanics with $E = mc^2$ rather than with falling apples and swinging chandeliers.

Another obstacle in the search for a simple approach to quantum theory has been the current philosophy that the task of physics is to find a rational description of the interrelations between phenomena, and that the quest for an explanation is futile. Although this may be true in the last analysis, it can hardly be said that modern quantum theory is yet in a state of representing last and irreducible principles. To accept duality, uncertainty, and complementarity as inscrutable articles of faith may have had its advantage in the beginning when physicists were groping for any solid ground to build upon. But to persist in this attitude is sterile in the long run and dangerously close to medieval scholasticism. Fundamental knowledge has never yet made progress at times when the return to common sense was received with a condescending smile at such naivety.

The following attempt at an 'acute analysis of our ordinary common-sense thinking' will start from considerations which seem at first sight to have little to do with quantum theory, since they do not even contain any mention of Planck's constant h. They try rather to exploit a common experience, namely, the fundamental fact that the effect should be a continuous function of the cause, or that an infinitesimal cause should never be able to produce a finite effect. Our programme is to show that such a continuity of cause and effect, which is a common experience, implies that on a microscopic scale there must occur discontinuous events which are controlled by probability rather than by cause-effect chains (see section I). The question then arises whether there may perhaps be definite laws connecting, if not individual events, at least statistical groups of events. But such groups, too, are only loosely connected, and there is no single-valued relationship between the probabilities of various events. Instead of trying to formulate the ambiguous relationship between definite probabilities, it is convenient first to introduce ambiguously defined 'probability amplitudes,' ψ, which are nothing but vectors giving a direction to the transitions from one state to others, and are interconnected by a well defined relation law (see section II). We hope to make the essential points of these considerations understandable by means of a familiar geometrical analogy, and to lift the curtain of mystery which has always shrouded the ψ's because of the customary representation by complex symbols.

Sections I and II present a fundamental but empty framework of formal relations between probabilities, which must be filled with concrete substance, namely, with a dynamical theory of actual mechanical systems possessing energy, momentum, and position in space and time. It is only here that the quantum h makes its appearance (section III). Planck's constant was introduced first in radiation theory through the oscillator rule $E = h\nu$, then in Bohr's quantization of orbits, and finally in the improved quantum prescriptions of Schrödinger, Born, and Heisenberg. But all these rules were invented *ad hoc* for the purpose of establishing a fundamental periodic relation between energy and time, and between momentum and space co-ordinates. This periodicity has always been, and still is, the most puzzling feature of micromechanics, although the experts, after long years of using it daily, seem to have forgotten its highly problematic character. Thus, after fifty-five years of quantum research, the question of why an oscillator emits energy quanta $h\nu$, formerly answered by 'because the Planck equation says so', is now answered by 'because the Schrödinger equation says so', in agreement with the experimental facts. It is the object of this article to point out that a more satisfactory reply can be given if one will try to lay bare the simple and elementary roots of the quantum theory.

I. TRANSITIONS BETWEEN STATES

We start from an analysis of the contrast between equality and inequality of physical objects. Imagine two gases, composed of the same kind of particles. Those of gas A may be of spherical shape, those of gas B may be distorted to ellipsoids. Are these two gases alike or unlike? Better, are they distinguishable or indistinguishable? Still more realistically, are they separable or inseparable by some sort of selective device if the two gases are mixed? The expected reply will be: When $A = B$ or, in our example, when the ellipsoids degenerate into spheres, then A and B are indistinguishable and inseparable. But when B differs physically from A even to an ever-so-small degree, then they are unlike and separable, at least in principle. However, this reply is in serious conflict with the general experience that the effect is a continuous function of the cause. Indeed, imagine a selective device—call it an A-filter—which passes the A-particles and blocks the B-particles, or is capable in some other way of separating the A's from the B's. Now suppose the difference between A and B to be gradually decreased; the A-filter still blocks the B-particles.

But the moment when B is made exactly equal to A then the A-filter will suddenly pass all B's. That is, an infinitely small cause, the changing of the difference between A and B from ever-so-small to exactly zero, would have a finite effect, a change from none passing to all passing. One feels intuitively that such an abrupt change of the effect is 'unphysical', that filters discriminating in such a drastic fashion between ever-so-small and exactly zero cannot exist in nature. The serious difficulties which such filters would entail in the domain of thermodynamics (second law) were pointed out by J. W. Gibbs in the 1880's. But Gibbs did not make the positive inference, which would have brought him to the doorstep of quantum theory, that hence there ought to exist a continuity of intermediate cases between $B = A$, where all B's are passed by an A-filter, and B being quite different from A (written $B \neq A$) where all B's are blocked by the same A-filter. There ought, indeed, to exist a continuity of possible states B of a 'fractional equality' with A, written $B \sim A$, such that the particles in the state B neither all pass nor are all rejected by the A-filter. $B \sim A$ would signify that a certain statistical fraction of the B's will pass and the remaining fraction will be rejected by the A-filter. This is, indeed, the only way of establishing continuity between none passing and all passing when the state B is gradually made to approach the case $B = A$, and thus avoiding the thermodynamic paradox of Gibbs.

The two limiting cases $B = A$ and $B \neq A$ (the latter also written $B = non\text{-}A$ or $B = \bar{A}$) are illustrated in figures 1(*a*) and 1(*b*). The intermediate case $B \sim A$ is shown in figure 1(*c*). The statistical passing-fraction P in the latter case may be taken as the operational definition of the fractional equality between the states A and B. The same passing-fraction P then represents the probability fraction for an individual B-particle to pass, and $1 - P$ the probability fraction of B being rejected.

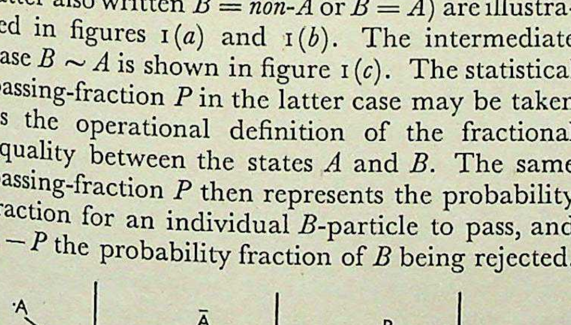


FIGURE 1

Without appealing to *ad hoc* hypotheses and without using microphysical evidence, but merely on grounds of the postulate of continuity of cause and effect, we have thus arrived at a basic tenet of the quantum theory, namely, that there must be states B of a mechanical system (particle, atom, etc.) intermediate between A and *non-A* such that an A-passing device will neither pass all B's nor reject all B's, but will transmit or reject B's according to a probability ratio, $P/(1 - P)$.

Whenever we see a group of particles passing an A-filter, then we are entitled to conclude that the particles of this group are in the state A so that they will pass an A-filter again and again, unless perturbing causes change their state A to some other state. On the other hand, we had come to the conclusion that, in case of $B \sim A$, only a certain statistical fraction P of the incident B-particles will pass the A-filter. But according to what was said just before, this entire group of A-passing particles must now be in the state A. Hence this group must have carried out a transition, must have 'jumped' from their original state B to the new state A (and then remained there unless further perturbed). These jumps from B to A may be ascribed to the reaction of the B-particles to the A-filter which, after turning them from B to A, will then let them pass. But similarly, the remaining fraction $1 - P$ of incident B-particles which is rejected must have jumped in contact with the A-filter to the state $\bar{A}$ and remain there unless further perturbed. The newly acquired states A and $\bar{A}$ in the passed and rejected group respectively are indicated in figure 1(*c*). The plausibility that this figure represents the effect of the A-filter on incident B-particles is enhanced by the consideration that one could hardly think of any other way of satisfying the continuity principle, with figure 1(*c*) representing cases intermediate between the limiting cases of figures 1(*a*) and 1(*b*). The passing-fraction of B-particles through an A-filter (figure 1(*c*)) then becomes the probability of transition from the original state B to the new state A in contact with the A-filter. We denote this probability as $P(B \rightarrow A)$ or shortly as $P(B,A)$. Reasons of thermodynamic equilibrium require that $P(B,A)$ equals $P(A,B)$, i.e. the passing-fraction of B-particles through an A-passing filter is as large as the passing-fraction of A-particles through a B-passing filter. This symmetry of the passing-fractions and transition probabilities is an important feature of the quantum theory.

Consider an example. Let A stand for a state of position of a particle within a small volume element surrounding a certain point in space, and let B denote a certain energy value of the same particle, e.g. of the electron in a hydrogen atom.

Suppose the electron has been ascertained to be in the energy state B and is now tested with a gauge having a hole (symbolically speaking) at the place A. The particle will 'pass' with probability P and will be blocked with probability $1 - P$.

Another interesting case is that of B being a state of orientation of a silver atom parallel to the z-axis, the A-filter being an inhomogeneous magnetic field of z'-direction making an angle with the z-direction. This 'filter' of Stern and Gerlach compels the incident atoms to choose either the $+z'$-orientation and pass, or the $-z'$-orientation and not pass, i.e. to emerge in a different direction, so that the atoms in the new states $+z'$ and $-z'$ are separated.

A great deal more ought to be said about those selective devices or filters and about the various states; the latter are always meant to be well defined states. For example, a state of position at xyz of a particle is not a well defined state, but position at xyz at a certain time t is. In this short article there is no room to elaborate on the fact that only well defined states are interconnected by definite probability fractions $P(A,B)$ = transition probabilities. Most filter tests are *Gedanken*-experiments hardly capable of being carried out directly; the importance of the Stern-Gerlach experiment was that it yielded the first direct confirmation of the actual existence of distinct quantum states and their statistical interrelation.

In general, a state is in a relation of fractional equality, $0 < P < 1$, to other states, and cases of total inequality, $P = 0$, are the exception. This fact can be used for bringing a certain order into the chaos of all (well defined) states of a mechanical system. From an indiscriminate list of all states one may pick out a set of states denoted as $A_1A_2A_3 \ldots$ which are mutually quite unequal, i.e. separable by filters, or, to use the technical expression, are mutually orthogonal. From the remaining states one may pick out another set of mutually separable or orthogonal states $B_1B_2B_3 \ldots$, then a third orthogonal set of states $C_1C_2C_3 \ldots$, and so forth, until all states of the mechanical system (particle, atom, molecule) are arranged in orthogonal sets:

$$\left.\begin{array}{l}\text{Set A: } A_1A_2A_3 \ldots \\ \text{Set B: } B_1B_2B_3 \ldots\end{array}\right\} \cdots\cdots\cdots \text{(I}a\text{)}$$

and so forth. Whereas a state A_k is totally different (separable) from any other state of the same set A, there are fractional equalities $P(A_k,B_j) < 1$ between the states of the set A and those of the set B, measurable as transition probabilities in statistical experiments with filters as described before. The following table lists the passing-fractions or probabilities of transition between the states of the sets A and B:

$$\left\{\begin{array}{cccc}P(A_1,B_1) & P(A_1,B_2) & P(A_1,B_3) & \ldots \\ P(A_2,B_1) & P(A_2,B_2) & P(A_2,B_3) & \ldots \\ \ldots & \ldots & \ldots & \ldots\end{array}\right\} \cdot\cdot \text{(I}b\text{)}$$

$$\text{abbreviated} = \{P(A,B)\}$$

Similar tables or 'matrices' may be written down for the transition probabilities from the states A to C, from B to C, and so forth. For reasons of the entropy law of thermodynamics the sets of (Ia) must all have the same number of members, hence the tables (Ib) are squares. And they are magic squares, in so far as the sum in any one row and in any one column has the same value, unity, since the P's are probabilities.

Starting from the postulate of continuity which requires a continuous scale of equality values between states we have taken a long stride into the general theory of transitions between states controlled by probabilities; we have thus deduced the background of the quantum theory. Of course, from considerations of such a general character it is not possible to obtain information about the exact magnitudes of the various probabilities P listed in the various P-tables; they will depend on a more specific definition of the states A and B in physical terms.

II. PROBABILITY AMPLITUDES

From the probabilities we now proceed to those probability amplitudes which have been a stumbling block to a common understanding of modern quantum theory and 'are looked upon as a ghost that produces material manifestations' (Lennard-Jones [2]). However, a simple geometrical analogy may lead to a better understanding of this subject.

Consider a triangle ABC and suppose that two of its sides, P_{AB} and P_{BC}, are given. These do not determine the length of the third side P_{AC}, since the latter depends also on the angle between the two others. Yet although there is no definite general relation between the three sides in a triangle, there certainly is some loose connection between them. In particular, the third side can never be larger than the sum of the two others:

$$P_{AC} \leqslant P_{AB} + P_{BC} \cdots\cdots\cdots\cdots \text{(II}a\text{)}$$

This triangular inequality determines the metric relation between points A, B, C only in a loose fashion. For example, the exact relation

$$P_{AC} = (P^2{}_{AB} + P^2{}_{BC} - 2P_{AB}P_{BC}\cos\beta)^{\frac{1}{2}}$$

is multivalent because of the free angle β. When the points are confined to a straight line, then

$$P_{AC} = |P_{AB} \pm P_{BC}|$$

is bivalent; the same holds when the points are on the circumference of a circle. However, with or without such restrictions one can replace the general inequality (II*a*) between quantities P by an equation for less definite quantities ψ in the following fashion. With every length $P_{AB} = P_{BA}$ associate a vector $\psi_{AB} = -\psi_{BA}$ of magnitude $|\psi| = P$ but of free direction. Then adjust the directions in every triangle so that the vectors will satisfy the addition theorem:

$$\psi_{AC} = \psi_{AB} + \psi_{BC} \cdots\cdots\cdots\cdots (\mathrm{II}b)$$

This vector equation is self-consistent and general. For example, one can replace the intermediate point B by any other point D. But the fact that one can write down and use this vector equation (II*b*) does not give any new insight into geometrical relations which were not already known before; geometers from Pythagoras to Riemann have made their discoveries without explicitly using the vector addition theorem (II*b*). They did not need to, since the latter is implicit in the geometry of distances. Vector rules are elegant formulations, not new geometrical discoveries, and even less do they represent new laws of physics. If it is found that the vector addition rule (II*b*) is always true in regular and irregular, big and small, triangles, this is not a surprising new fact but a matter of definition, since the vectors can be, and always are, adjusted in their directions so that they will satisfy the addition law. Incidentally, if the points A, B, C . . ., and hence the vectors, are all in one plane, then one can denote the latter by a complex symbol, $\psi = |\psi|e^{i\alpha}$, where α is the directional angle; but this does not imply that vectors are complex entities.

We now return to the transition probabilities P listed in the table $\{P_{AB}\}$ and in similar tables $\{P_{AC}\}$, $\{P_{BC}\}$, and so forth. The probabilities P satisfy the general inequality:

$$P(A_k,B_j) \leqslant 1 \;\ldots\ldots\ldots\ldots (\mathrm{II}c)$$

and they obey special relations:

$$\begin{aligned} P(A_k,A_{k'}) &= 0 \text{ for } k \neq k' \ldots\ldots (\mathrm{II}d) \\ &= 1 \text{ for } k = k', \end{aligned}$$

characterizing the members of the set A as mutually orthogonal or separable states. The P's also satisfy the magic square rule that the following sums are unity:

$$\Sigma_j P(A_k,B_j) = 1 \text{ and } \Sigma_k P(A_k,B_j) = 1 \,..\, (\mathrm{II}e)$$

As with the geometrical problem, one may ask whether there is a general relation or equation between the P's occurring in $\{P_{AB}\}$, $\{P_{BC}\}$, and $\{P_{AC}\}$. This relation must be of such a form that the general summation rule (II*e*) will be satisfied in the table $\{P_{AC}\}$ when it is satisfied in the tables $\{P_{AB}\}$ and $\{P_{BC}\}$. Actually, it is possible to write down a relation between the three P-tables which automatically satisfies this condition in the following way.

Associate with every quantity P a vector ψ, in this case of magnitude $\sqrt{P}$ and of an indefinite direction α in a plane; two vectors $\psi(A_k,B_j)$ and $\psi(B_j,A_k)$ shall have directional angles α and $-\alpha$ respectively, although the corresponding magnitudes $\sqrt{P}(A_k,B_j)$ and $\sqrt{P}(B_j,A_k)$ are the same. Then adjust the vector directions so that the following multiplication rule is satisfied:

$$\{\psi_{AC}\} = \{\psi_{AB}\} \times \{\psi_{BC}\} \ldots\ldots\ldots (\mathrm{II}f)$$

(compare with the addition rule in the geometrical analogy). The multiplication sign × denotes a so-called matrix multiplication, (II*f*) being an abbreviation for

$$\psi(A_k,C_m) = \Sigma_j \psi(A_k,B_j)\psi(B_j,C_m) \;\ldots . (\mathrm{II}g)$$

Since the vectors are all in one plane we use the complex notation $\psi = |\psi|e^{i\alpha}$, and the products on the right of (II*g*) are understood to be carried out according to the rules of complex quantities. But these are details: the essential point is the following. Just as in geometry one can replace the loose connection (II*a*) between three lengths P in a triangle by an equation between vectors the directions of which are adjusted to satisfy this addition law, so one can replace the loose connection between three tables $\{P\}$, expressed by the conditions (II*e*) valid for all three of them, by an equation between vectors whose directions are adjusted so that they will satisfy the matrix multiplication law (II*f*), or (II*g*), the latter being known as the ψ-superposition law. But neither the vector addition of geometry nor the matrix multiplication or superposition of probability amplitudes can be considered as a new and independent law of nature. If there are metric relations between the lengths P at all, then to the mathematician the vector addition in a triangle is a matter of course, and to him it is equally a matter of course (not a new independent fact) that sets of entities (I*a*) characterized as orthogonal by the P-relations (II*d*) and satisfying the sum rules (II*e*), if interrelated at all, should be interrelated by unitary orthogonal transformations, namely by the ψ-equations (II*f*, *g*). The latter are only an elegant formulation of the P-metric if one assumes that there is a general metric of real probabilities at all, i.e. if one believes that Nature is a cosmos rather than a chaos. But due to the habit of representing vectors in a plane by complex symbols, which is commonplace in practical electrical problems, the myth has spread that there is something eerie about those complex quantities ψ, which, in spite of their elusive unreality, lead to experimentally confirmed results almost by magic. Thus the student believes that quantum theory is far above the comprehension of the common man—which may be true for the mathematical details but is not true for the underlying ideas.

He will be confirmed in his belief in the incomprehensibility of quantum theory when he is told further that the symmetry principles governing the interaction between identical particles (between two or more electrons, two or more helium atoms, etc.) present us with 'some aspect of great philosophical content beyond the understanding of the physicists . . . who must be content to accept the implications without hoping to penetrate the mystery that is implied': again we quote Lennard-Jones, whose work led to most valuable insights into those very implications. But it is hard to see why it should be beyond the understanding of the physicist that two like particles a and b form a system in which the probability of finding a at x_1 and b at x_2 is equal to the probability of finding a at x_2 and b at x_1. It is not cryptic but natural that identical particles should play a symmetrical role when observation is in question. Taking this symmetry of the observable probability for granted, it then follows that the corresponding probability amplitudes must be either symmetric or antisymmetric; that is, the vector ψ must either remain the same or change its direction from α to $-\alpha$ when a at x_1 and b at x_2 is replaced by a at x_2 and b at x_1. From this symmetry of the probability P one arrives at such further results as the resonance forces between identical particles, the Pauli exclusion and the Bose accumulation principles (which from this point of view are not principles but consequences), the two quantum statistics, and many other phenomena. The symmetry principles are part of the general theory of probability relations, more general than the h-dominated quantum dynamics of conjugate quantities q and p.

III. QUANTUM DYNAMICS

The structural framework of the quantum theory developed in the previous sections does not even mention the quantum constant h. The Planck constant occurs only when one proceeds to specifically defined states of real mechanical systems characterized by various co-ordinate values q at various times. Planck's original quantum hypothesis $E = h\nu$ postulated a quantized periodic relationship between energy and time. Later Bohr, Sommerfeld, and Wilson introduced corresponding relations between a space co-ordinate q and its conjugate momentum p, thus initiating the era of quantized orbits. However, these quantum conditions were introduced as *ad hoc* hypotheses in order to explain atomic phenomena, and physicists tried hard to detect reasons for this strange periodicity within the framework of classical mechanics. Only when all attempts in this direction had failed did they wisely decide that the time was not ripe for an explanation of the quantum rules, and that one should accept them as axiomatic. But this attitude, which was reasonable as a temporary expedient, hardened into the creed that the quantum rules themselves are fundamental, are irreducible to anything more elementary, and not even in need of further justification. Then in 1926 new and better rules were found, viz. the Schrödinger operator rule, $p = (h/2i\pi)\mathrm{d}/\mathrm{d}q$, and the Born commutation rule, $qp - pq = h/2i\pi$. These rules again postulate a periodic relationship between co-ordinates and their conjugate momenta, though in a form more intricate than the older prescriptions of Planck and Bohr. But this periodicity is still the chief enigma of the quantum theory; every student is puzzled by it, and only when the experts tell him that there is no further explanation—nor even the need for an explanation—does he slowly resign himself to accept the quantum rules of periodicity as a matter of fact. Yet there is no necessity for this attitude of resignation. Instead of introducing the quantum rules of Born and Schrödinger as new and independent assumptions, supplementing the general ψ-superposition rule (IIg)—that is, instead of introducing the wave mechanics of Schrödinger or the matrix mechanics of Born and Heisenberg by decree on grounds of microphysical evidence—one can show that the quantum postulates of Born and Schrödinger, with their periodicity, are mathematical consequences of the general ψ-superposition (probability metric) applied to the special case of quantities q and p as conjugates, if conjugacy is defined in the following manner:

Imagine an assemblage of many independent particles, all in the same external force field. The original position and momentum values q_0 and p_0 at time t_0 may vary from particle to particle, but all initial qp-values represent points within a certain volume range V_0 of the whole qp-space, or 'phase space.' In the course of time the various qp-points will move to other places in phase space where they will occupy other volumes V at other times t. The classical equations of motion now yield the simple yet important result that the volumes V occupied at various times t will all have the same magnitude, or $V = V_0 =$ constant. This is the well known Liouville theorem of classical mechanics. Statistically, over a long time interval, the probability of a member of an assemblage of particles residing in V_0 is as large as that of residing in V when $V = V_0$. In short, there is a constant probability density in qp-space. This result of classical statistical mechanics is very general; it holds not only for particles, but also for systems of particles, atoms, molecules, and mechanical systems in general. It is a statistical result, though resting on the deterministic equations of motion.

Now, although deterministic mechanics must be abandoned in favour of a statistical theory (for the sake of cause-effect continuity, section I), classical mechanics is not quite wrong. It is in every way most plausible, in these circumstances, that the one feature of classical mechanics to be preserved in the new statistical theory should be the statistical result of the constant probability density in qp-phase space. That is, in classical as well as in the new mechanics, two quantities q and p can be defined as mutually conjugate when they possess a constant probability density in qp-space. To this must be added the familiar fact that only co-ordinate differences and momentum differences rather than absolute q and p values, have a physical significance.

When the ψ-multiplication rule of section II is applied to conjugates q and p as defined above, then it becomes a mathematical necessity [4] that the vector $\psi(q,p)$ must have a constant magnitude for all values of q and p, and that its directional angle must change in proportion to q for given p, and in proportion to p for given q. After a change of 360° the original vector ψ is encountered again; that is, ψ is periodic in q as well as in p. When the vector ψ is written in complex notation the same result reads:

$$\psi(q,p) = \exp\,(2i\pi qp/\text{constant}) \ldots. (\text{III}a)$$

It is the simplest case of a Schrödinger wave function. The constant denominator is usually denoted by the now familiar letter h.

The reader will notice that neither the constant probability density in qp-space nor the ψ-multiplication or superposition rule assume any periodicity. Only when taken together do they require q and p to occur in the periodic probability relation (IIIa) with wavelength $\lambda = h/p$. The strange quantum periodicity is thereby explained, that is, reduced to a simple and almost common-sense non-quantal background, rather than ascribed to principles of duality and complementarity of cryptic origin. Of course, deciding what is strange and what is of a common-sense character is a matter of personal judgment. It is after all very simple to write down formulas such as the Schrödinger operator rule or the Born commutation rule—so simple indeed that many have forgotten that the periodicity of quantum theory in itself is of a problematic character. The present article has tried to show that quantum theory can indeed be understood as a consequence of the non-quantal principle of cause-effect continuity which leads first to the general probability metric of sections I and II, and yields, when applied to conjugate co-ordinates and momenta, the periodic probability relation between conjugates which is the most essential feature of the quantum theory.

REFERENCES

[1] BRIDGMAN, P. W. *Sci. Mon., N.Y.*, **79**, 32, 1954.

[2] LENNARD-JONES, J. *Ibid.*, **80**, 175, 1955.

[3] LANDÉ, A. 'Foundations of Quantum Theory, a Study in Continuity and Symmetry'. Yale University Press, New Haven. 1955.

[4] LANDÉ, A. *J. Phys. Radium*, **17**, 1, 1956; *Amer. J. Phys.*, **24**, 56, 1956.

Insect song

J. W. S. PRINGLE

The sounds made by different species of insects, or by members of the same species in different moods, are characterized by differences in the time distribution of pulses of sound rather than by differences in pitch or tone quality as with birds and mammals. The inability of the human ear to distinguish this significant feature has long obscured the rich variety of insect songs, but modern recording devices have made it possible to analyse them in detail.

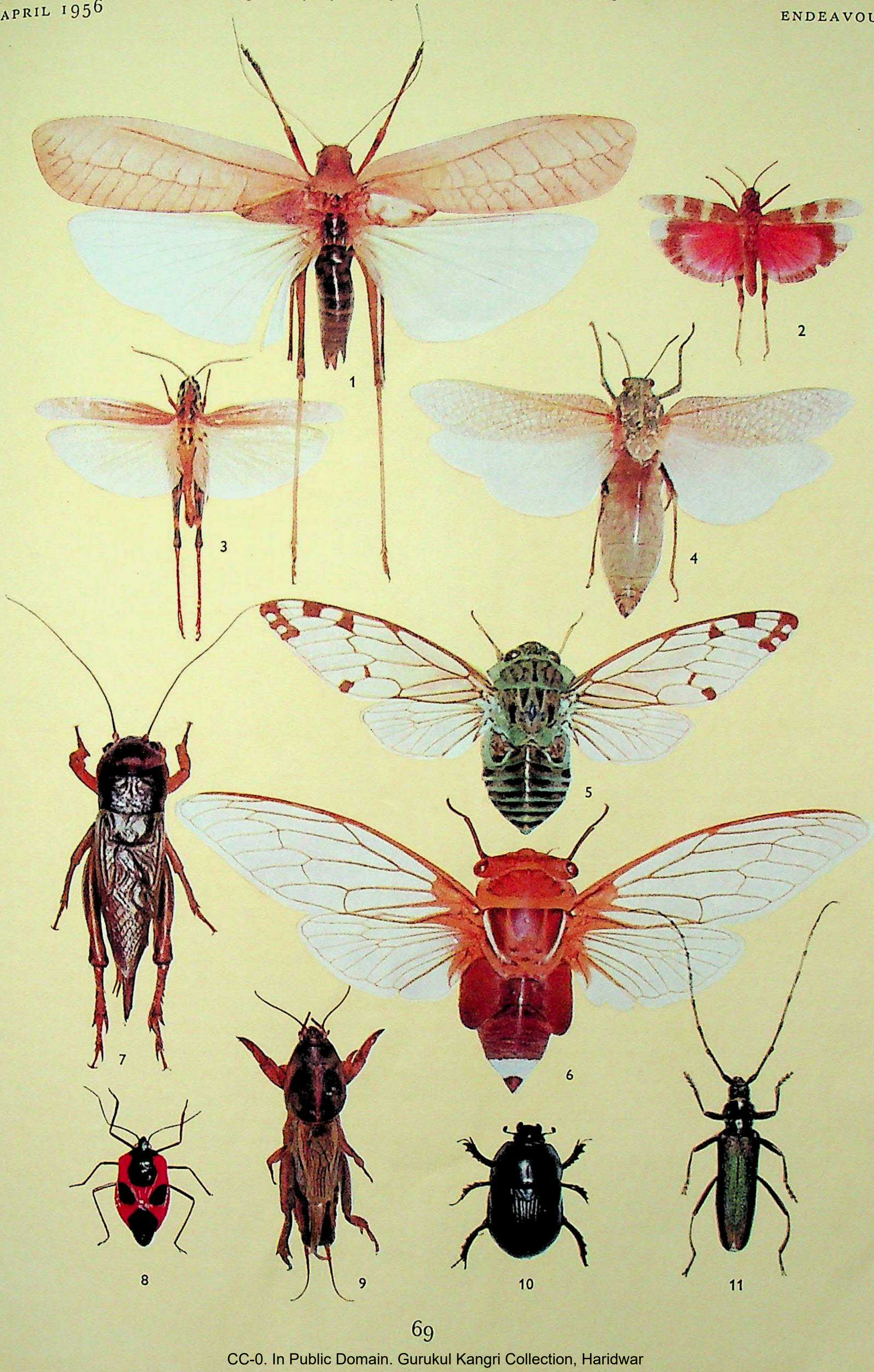
The Sinhalese name for the cicada is *Răhaiya*, meaning 'a hundred nights', and is derived from the belief that the insects sing for that period of time and then burst. The villager will point out on the trunks of trees cicadas that have suffered this fate; they are, in fact, the split nymphal skins from which the adult has emerged after several years of subterranean existence. All over the world there is a similar picturesque legendry wherever there are insects that have forced themselves on the notice of man by their capacity to produce sounds.

The most elaborate patterns of song and the most complicated organs for sound-production are concerned with mating behaviour. Provided that the other sex has sense organs capable of receiving the sound and of determining the direction of its source, a means is provided by which insects in the correct physiological condition can be brought into close proximity; other, usually visual, stimuli can then assume control of the movements of orientation and coition. As with all other animals except man, sound-production is thus an indication of mood—of that combination of internal states which renders the insect ready for a particular behavioural act; the abstract symbolism characteristic of human speech [8] is, so far as is known, absent in insect songs. Moods other than sexual preparedness may be associated with sound-production. This applies especially to alarm, when the noise may deter a predator or warn other members of the species, but in insects, as in birds [4], the sounds produced under these conditions tend to be simpler and less specific than those concerned with mating.

In recent years much progress has been made towards an understanding not only of the role that sounds play in the behaviour of insects, but also of the physical and physiological mechanisms involved in sound-production. In many respects these differ fundamentally from the method used by the other great group of land animals, the Vertebrates. Insects have no respiratory airstream capable of inducing passive vibration in structures like the vocal cords, whose operation is analogous to that of the reed of a clarinet. Their hard exoskeleton and internal tracheal air spaces, however, provide an ideal sounding-board, capable of efficient transformation of vibrational energy into airborne sound. It is possible that this provides the key to an understanding of the many strange freaks of structural evolution found in insects, for vibrations are readily produced whenever two parts of the body come in contact, or by buckling of the skeleton due to the contraction of muscles attached to it. Both in cicadas and in several groups of the Orthoptera, comparative studies can suggest a probable course of evolution of the sound-producing habit through the addition of a resonator to a vibration-generating mechanism.

Figure 1 shows examples of some well-known insect singers. Numbers 1–4, 7, and 9 are Orthoptera; 5 and 6 are cicadas (Homoptera); 10 and 11 are beetles (Coleoptera); and 8 is a Pentatomid bug (Heteroptera). All except the cicadas produce sound by the rubbing of one part of the body on another (stridulation), one part often having a ribbed or toothed file which increases the contact resistance. Cicadas utilize the buckling of a specially modified region of the skeleton on the dorsolateral wall of the first abdominal segment; this is effected by means of a large pair of muscles inserted

FIGURE 1 (*see facing page*) – *Some insects which produce sounds.* (*Natural size*). (1) Anaedopoda lamellata (*L*), *Tanganyika*. (2) Oedopoda germanica (*Latr.*), *Europe*. (3) Scyllina picta (*Bruner*), *S. America*. (4) Pneumora variolosa (*L.*), *S. Africa*. (5) Zammara smaragdina (*Walk.*), *Mexico*. (6) Thorpha sessiliba (*Dist.*), *Australia*. (7) Brachytrypes portentosus (*Licht.*), *India*. (8) Catacanthus violarius (*Stål.*), *New Guinea*. (9) Gryllotalpa gryllotalpa (*L.*), *Europe*. (10) Geotrupes stercorarius (*L.*), *Britain*. (11) Aromia moschata (*L.*), *Britain*.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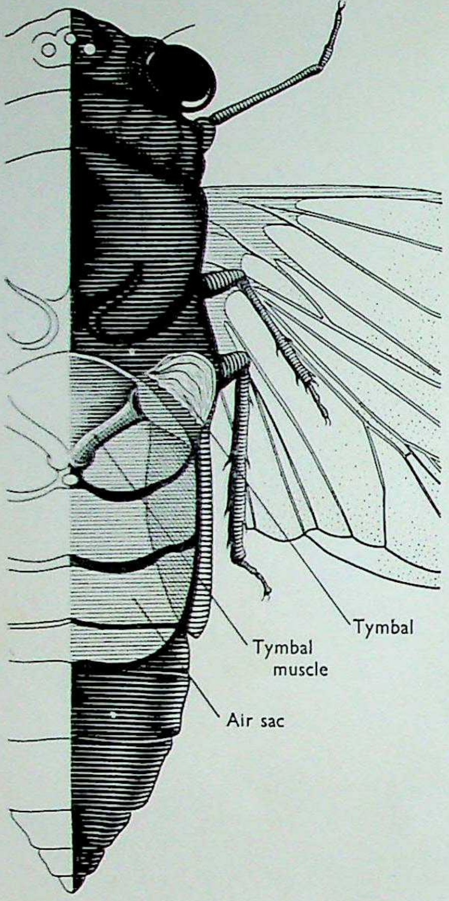

FIGURE 2 – *The sound-producing organs of a cicada* (Platylomia abdulla (*Dist.*)) *seen through a window cut in the abdominal dorsum; the tymbal cover has been removed.*

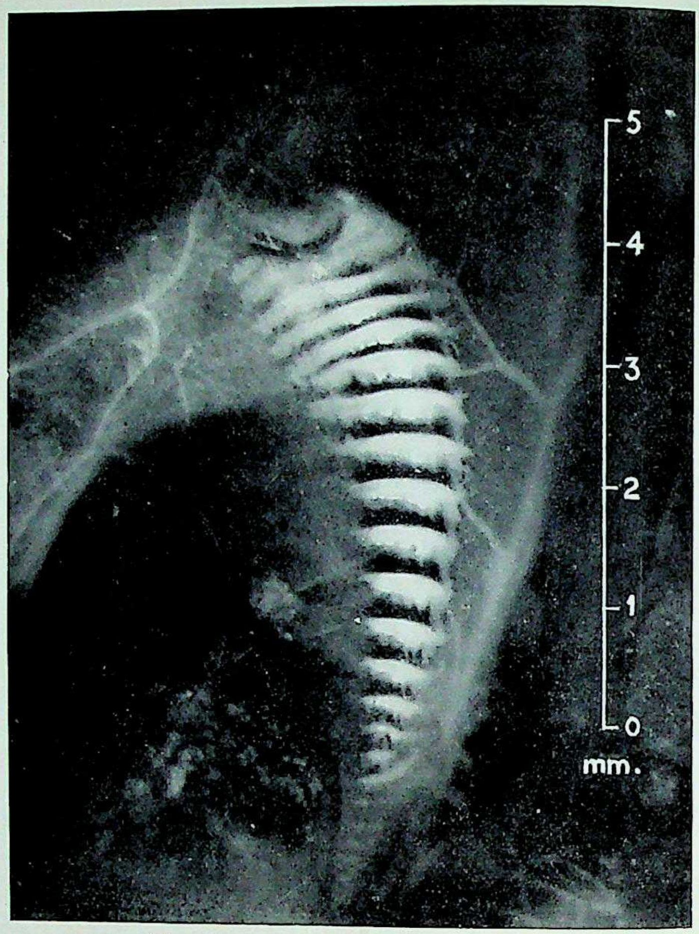

FIGURE 3 – *Photomicrograph of the abdominal stridule of* Prestalia granulata (*Stål.*) (*Pneumoridae*).

by a slender apodeme in one corner of the 'tymbal' (figure 2). The structure can be seen in *Zammara smaragdina* (figure 1 (5)), but more usually, as in *Thorpha sessiliba* (figure 1 (6)), it is covered by a protective fold of cuticle. The whole of the abdomen of the male cicada—only the male sings—is occupied by a large tracheal air space, which is tuned to the frequency of tymbal vibration when the abdomen is expanded by special accessory muscles; another accessory muscle can increase the curvature of the tymbal and so increase the intensity of the click produced when the surface buckles [6].

The file-and-peg method has many variations. In the crickets (Gryllidae, figure 1 (7 and 9)) the file is on the under-surface of the right wing and there is a peg on the left wing; the bases of both wings are strengthened to form a resonating membrane. In *Anaedopoda lamellata* (Tettigoniidae, figure 1 (1)) the file is on the under-surface of the left wing, and the right wing alone has a special vibrating membrane at its base. In the Acrididae the hind-legs are usually involved; *Oedopoda germanica* (Oedopodinae, figure 1 (2)) has the file on the wing, whereas in *Scyllina picta* (Truxalinae, figure 1 (3)) it is on the hind femur. In the male of *Pneumora variolosa* (Pneumoridae, figure 1 (4)) the hind-legs are again used, but the file is on the abdomen (figure 3) and there are large abdominal air-sacs analogous to those of cicadas. In the Coleoptera, sound may be produced by movement of the prothorax on the mesothorax (*Aromia moschata*, Cerambycidae, figure 1 (11)); by movement of the hind coxae (*Geotrupes stercorarius*, Scarabaeidae, figure 1 (10)); or by rubbing the tip of the abdomen on the elytra, as in the little water-beetle *Hygrobia hermanni* (Peloriidae), in which the sound can be made even under water. Sometimes

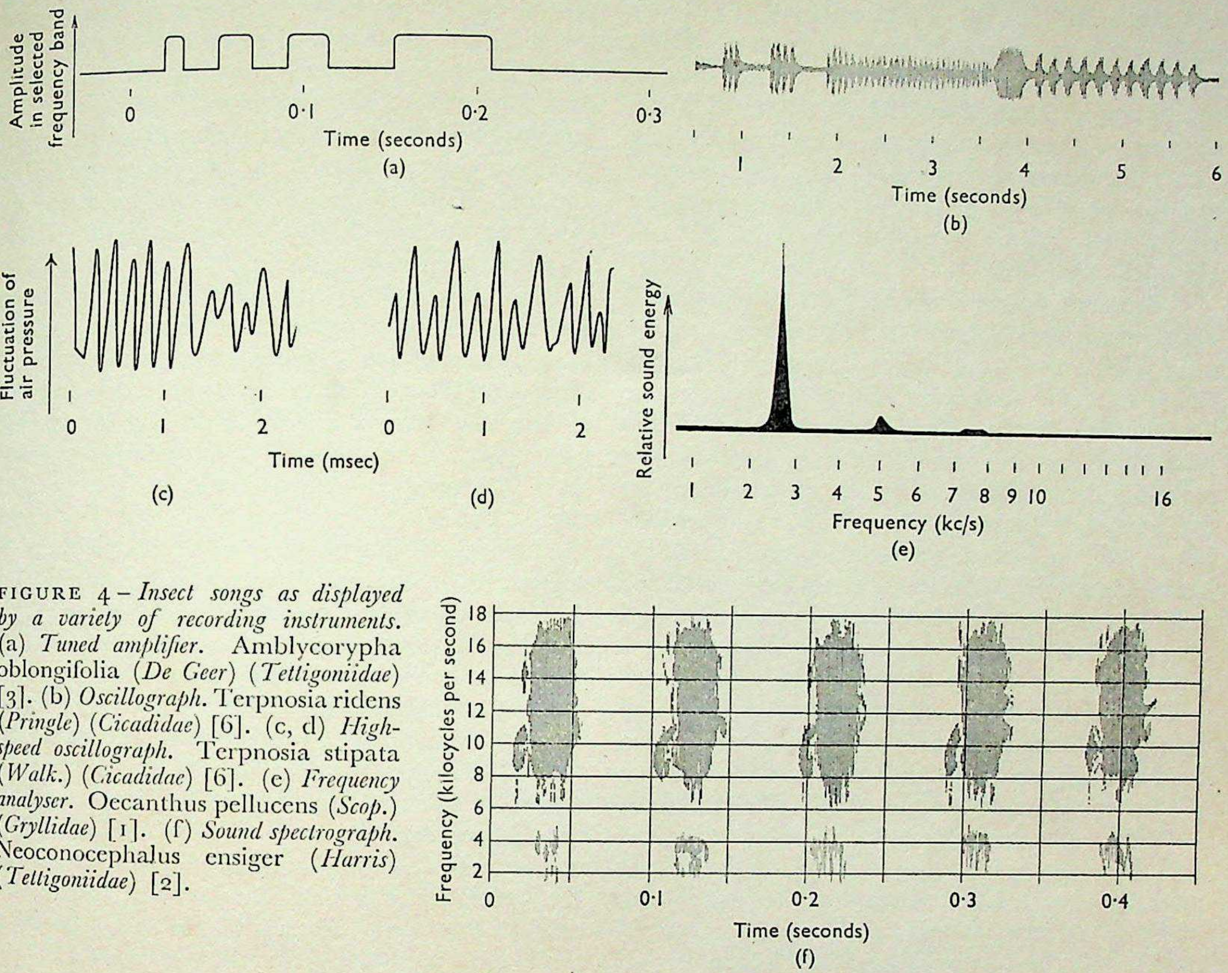

FIGURE 4 – *Insect songs as displayed by a variety of recording instruments.* (a) *Tuned amplifier.* Amblycorypha oblongifolia (*De Geer*) (*Tettigoniidae*) [3]. (b) *Oscillograph.* Terpnosia ridens (*Pringle*) (*Cicadidae*) [6]. (c, d) *High-speed oscillograph.* Terpnosia stipata (*Walk.*) (*Cicadidae*) [6]. (e) *Frequency analyser.* Oecanthus pellucens (*Scop.*) (*Gryllidae*) [1]. (f) *Sound spectrograph.* Neoconocephalus ensiger (*Harris*) (*Tettigoniidae*) [2].

the larvae also have stridulating organs and on capture produce a vibration which may well deter a foraging bird. There is an almost equal variety in the Hemiptera.

Not only are the methods of producing sound in insects different from those found in the Vertebrates, but the quality also is very different. This has been obvious to naturalists from the earliest times, but it is only with the use of modern recording methods that the characteristics have been fully elucidated. The small size of insects limits the frequency to which structures in their bodies can resonate, and high, even supersonic, frequencies are the rule (range 2·5 to 50 kc/s). The sound also tends to be broken up into a series of very short pulses at a frequency of 20 to 500 per sec., a feature which may be correlated with the fundamentally different physiology of the auditory organs. Whereas the ears of Vertebrates, at least in all the higher land-dwelling members of the sub-phylum, contain groups of cochlear nerve endings each sensitive to a slightly different frequency band and so conferring an ability to discriminate the pitch of a received sound, insect ears are either untuned or have a single overall band of frequency coverage and give a pattern of impulses in the auditory nerve which follows the modulation or amplitude envelope [7]. Sound to an insect thus has the function of a carrier wave, analogous to the radio-frequency oscillation in wireless telegraphy, and the information which is characteristic of the species or the mood is carried in the pattern of pulses rather than in pitch variations or tone quality as with birds and mammals. It is because of the inherent inability of the human ear to detect the significant features of many insect songs that the variety existing in nature has long gone unsuspected.

Four main types of recording instrument are now available which can be used in the study of insect songs, and the records which these give are illustrated in figure 4. The time-pattern can be determined with a tuned amplifier; figure 4(*a*) represents a single chirp in the song of an American katydid (Orthoptera, Tettigoniidae). A more rapid record would show each of these sounds to be composed of a series of pulses corresponding to the disengagement of one tooth on the file from the peg on the other wing; the chirp thus involves four movements of the wings. The frequency of emitted sound is not displayed by this method, but may be determined approximately from the tuning of the amplifier.

If the microphone is connected to a wide-band amplifier, a maximum of information about the song is obtained from the oscillogram. Figure 4 shows such an analysis of the song of a cicada. The pulses corresponding to the clicking of the tymbal occur in groups with a complicated rhythm; the 'phrase', which is characteristic of the species, is shown in figure 4(*b*). Fast oscillograms of the sound waveform within a single pulse (figure 4(*c*), (*d*)) indicate that the tymbal has several modes of vibration, chiefly at 2250 c/s and at the second harmonic, 4500 c/s, which is the resonant frequency of the abdominal air-sacs.

The third method, which is conveniently used as a complement to oscillography, is frequency analysis. Figure 4(*e*) shows the song of a cricket (Orthoptera, Gryllidae); insects of this family emit a musical tone purer than those of any other, the sound-frequency being determined by the rate of passage of the wing-file teeth over the peg, so that one pulse of sound is produced by an entire wing-stroke. The harmonic content of this song is very low, and the oscillogram of each pulse is a pure sine-wave. The frequency-analyser does not display the time-pattern of pulses in the song and, by itself, contributes little to an understanding of the features which are of significance to other insects.

The most refined apparatus is the sound-spectrograph or Vibranalyzer. This involves the making of a faithful magnetic recording of the song using a microphone, amplifier, and recording speed capable of noting the highest frequencies, and then analysing a loop by means of which the chosen phrase may be repeated indefinitely. The record made by the instrument (figure 4(*f*)) shows the time-pattern and frequency along the X and Y axes respectively, the intensity at any given frequency being indicated by the density of the print. A choice between maximum frequency resolution and maximum time resolution can be made by changing the bandwidth of the analysing filter. The song shown in figure 4(*f*) is that of a small Tettigoniid grasshopper; each note corresponds to one complete wing movement and is composed of a succession of rapid pulses corresponding to the number of file-teeth used. An appreciable fraction of the total sound energy is in the supersonic range, and the wide band of frequencies emitted gives the song a hissing quality to the human ear.

The file-and-peg method of sound-production necessitates elaborate structural adaptations but demands no major modification of physiology. The high frequencies in the song are produced by the resonance of membranes and by the use of serrations; the movement itself is not more rapid or more frequent than other movements made by insects. This is not the case with the tymbal system of the cicadas and their relatives among the Homoptera. In some cicadas the pulse frequency, which corresponds to the movements of the tymbal, may be as high as 400 c/s. In order to achieve this speed of contraction and relaxation the tymbal muscle has evolved a form of activity-cycle which is different from that of all other striated muscles except the indirect wing muscles of flies, bees, and certain other insects [5]. The rhythm of contraction is determined, not by the central nervous system but in the muscle itself, by a mechanism involving a deactivation of the contractile fibrils by the mechanical stimulus of the tymbal movement. The detailed nature of this process is not yet clear; its elucidation is perhaps the most important problem facing the zoologist in his search for an understanding of the physiology of insect song.

REFERENCES

[1] Busnel, R.-G., Busnel, M. C., and Pasquinelly, F. *C.R. Soc. Biol., Paris*, 148, 859, 1954.

[2] Borror, D. J. *Ohio J. Sci.*, 54, 297, 1954.

[3] Pierce, G. W. 'The Songs of Insects'. Harvard University Press, Cambridge, Mass. 1948.

[4] Marlar, P. *Nature, Lond.*, 176, 6, 1955.

[5] Pringle, J. W. S. *J. Physiol.*, 124, 269, 1954.

[6] *Idem. J. exp. Biol.*, 31, 525, 1954.

[7] Pumphrey, R. J. *Biol. Rev.*, 15, 107, 1940.

[8] *Idem.* 'The Origin of Language'. Liverpool University Press. 1951.

The gas-liquid chromatogram

A. T. JAMES

The great importance of chromatography needs no emphasis. The recent development of a new form of the method, depending upon selective distribution of substances between gaseous and liquid phases, has still further extended its range. Although applicable only to volatile substances, gas-liquid chromatography has a scope as wide as that of the various forms of distillation, which it closely resembles, since it can be applied to substances exerting a partial vapour pressure in the column as low as 1 mm of mercury.

In the course of time distillation has evolved into an elaborate technique for fractionating mixtures of substances having different volatilities. In essence the technique of fractional distillation is simple enough. Vapours derived from the boiling mixture are passed up a vertical column against a falling stream of condensed vapour, and the different components of the mixture distribute themselves between the vapour and liquid streams according to their relative volatility, the most volatile tending to concentrate at the top of the column and the least volatile at the bottom. To obtain the most effective separation it is necessary to pass the vapour and liquid phases through as many equilibrium stages or theoretical plates as possible, the latter being defined as that length of column in which vapour leaving the top is in equilibrium with liquid leaving the bottom. To attain this end, various devices are inserted into the column to promote the most intimate contact between the vapour and liquid streams. The smaller the length of the theoretical plate the more plates there are in a given length of column, and the easier it becomes to obtain pure fractions. The best laboratory fractionating columns may have efficiencies as high as 200 plates, but large-scale industrial columns are much less efficient.

Because the fractionating column is filled with the mixture to be separated, a substance leaving the column is followed immediately by the next; in consequence the fractions always overlap, the extent of the overlap depending on the efficiency of the column. From the industrial point of view this is no great defect, since the recycling of such fractions is easy. From the analytical point of view, however, it is much more serious, since a 100 per cent yield of any one component is impossible. An additional disadvantage for the analyst is that it is difficult to make a high-efficiency fractionating column capable of handling quantities of material less than 5–10 g. Furthermore, as the columns need to be run slowly, it takes a long time to obtain information about the number of components in a complex mixture.

One variant of distillation technique, known as carrier distillation, is to add to the mixture a chemically inert substance having a boiling point such that one component can be selectively removed in the distillate. This process has lately been modified in a novel manner by replacing the vapour of the carrier substance by a permanent gas and the liquid phase of the column by a non-volatile liquid. This non-volatile liquid is distributed over the surface of an inert porous solid, usually kieselguhr, that is packed into the column. The porous nature of this packing allows the permanent gas stream to be passed rapidly through the column with the aid of reasonably low excess pressures; the pressures used normally lie between 5 and 80 cm of mercury above atmospheric pressure. When a mixture of volatile substances is applied to the top of the column and is blown down by the gas stream it will separate into its components, in order of their relative volatility, in the stationary liquid phase. Provided the column is long enough, the substances emerge quite separately in the stream of gas which emerges from the end of the column. Such columns, with efficiencies of 1000–2000 theoretical plates, are easily constructed.

This system is in effect a form of chromatography, a gas-liquid form essentially similar in behaviour to the liquid-liquid (or partition) chromatography invented by A. J. P. Martin and R. L. M. Synge in 1941. It can be considered as the last form of chromatography to be applied, since now all the readily obtainable combinations of solid, liquid, and gaseous phases—liquid-solid, gas-solid, liquid-liquid, and gas-liquid—have been exploited. Martin and Synge suggested the feasibility of the gas-liquid chromatogram in their original paper on the liquid-liquid chromatogram,

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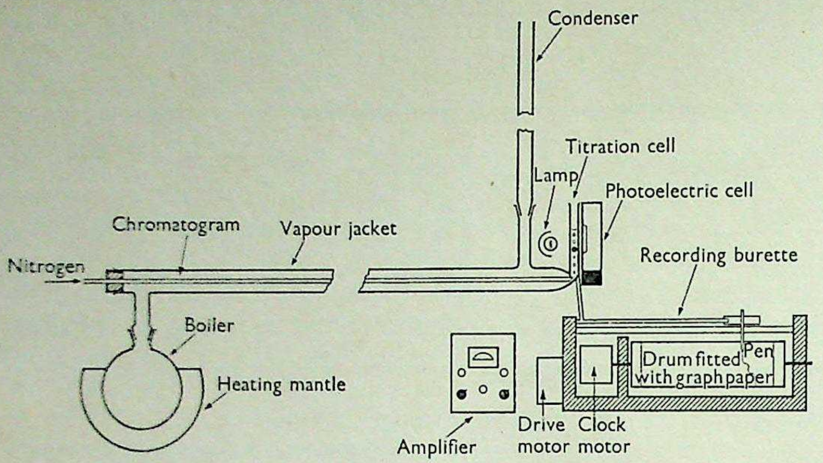


FIGURE 1 – *Schematic diagram of apparatus for gas-liquid chromatography, using automatic titration to detect volatile acids or bases emerging from the column.*

but it was not developed until ten years later [1]. The subject has been reviewed elsewhere [11–13] more fully than is possible here.

The use of a gas as the mobile phase of a chromatogram confers a number of advantages. (1) The high rate of diffusion in the gas allows equilibrium with the liquid phase to be attained rapidly; (2) the compressibility of a gas allows the use of long thin columns even at rapid rates of flow; (3) it is easier to detect vapours in permanent gases than solutes in solvents, particularly in the case of such unreactive substances as saturated hydrocarbons; and (4) high column efficiencies are attainable even at rapid rates of flow, so that precise separations can be carried out more rapidly than by any other technique.

On an analytical scale the apparatus is simple. It consists of a length of narrow glass or metal tubing packed with a mixture of the stationary phase and kieselguhr, maintained at a constant temperature by a vapour jacket. A source of nitrogen of constant pressure [1, 2] is applied to the column, the effluent from which is passed into a detector which records automatically the amount of vapour present in the gas stream.

Three methods of detection have so far been widely used: the first records the total mass of material (or some function of the mass) that has emerged, and the second and third record the concentration at which material is emerging.

A total-mass record—such as is produced by automatic titration (figure 1) of volatile acids or bases [1], or by volume measurement after removal of carrier gas [3]—will show a series of steps, representing the integrals of the more familiar peaks seen in chromatograms; some examples are shown in figures 3–5. Instruments which measure the concentration at which material is emerging from the chromatogram, such as catharometers [4–6] or the gas-density meter [8], show peaks on the final chart, and examples of their use are shown in figures 6–8. A typical apparatus is shown diagrammatically in figure 2.

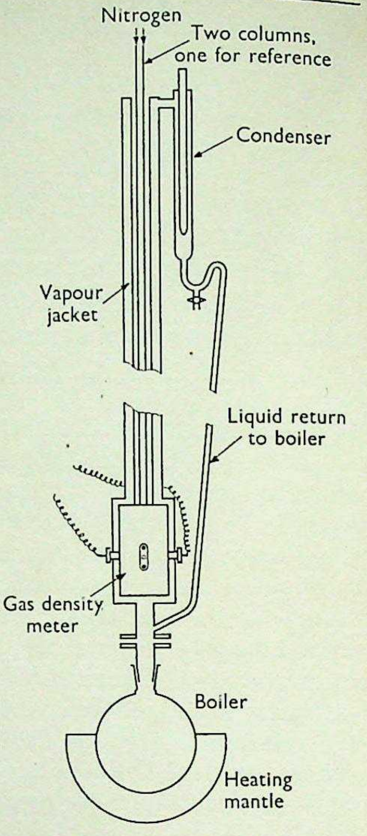


FIGURE 2 – *Schematic diagram of apparatus using automatic density measurement to record the presence of vapours leaving the column.*

THE ADVANTAGES OF THE GAS-LIQUID CHROMATOGRAM

As pointed out, these columns can be operated at high efficiencies even with rapid rates of gas-flow, so that separations can be carried out quickly. Figure 4 shows a separation of mono-, di-, and tri-methylamines completed in eight minutes, the record showing the relative amounts of each component. Analyses of more complex mixtures are shown in the other figures.

The high sensitivity of the technique allows the use of very small samples. Furthermore, the material leaving the apparatus can be recovered and subjected to further chemical study if required. The range of materials that can be handled is the same as that amenable to distillation, even at pressures down to 1 mm of mercury.

The apparatus can be made fully automatic, so that many analyses can be carried out with the

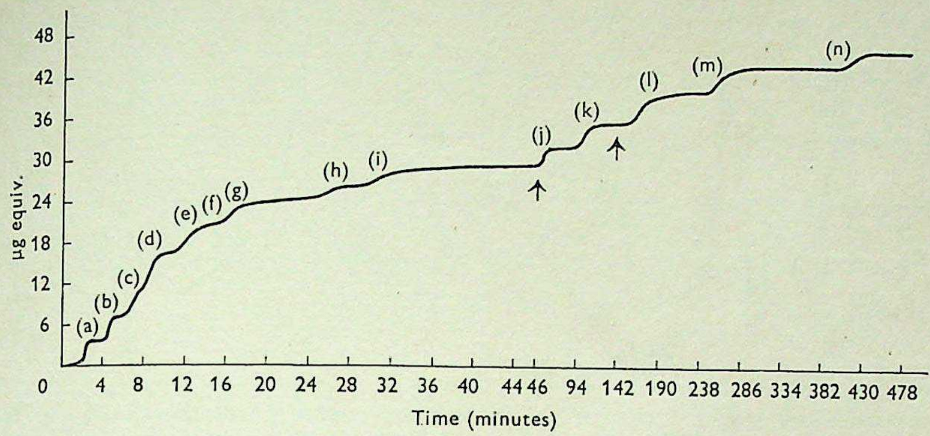
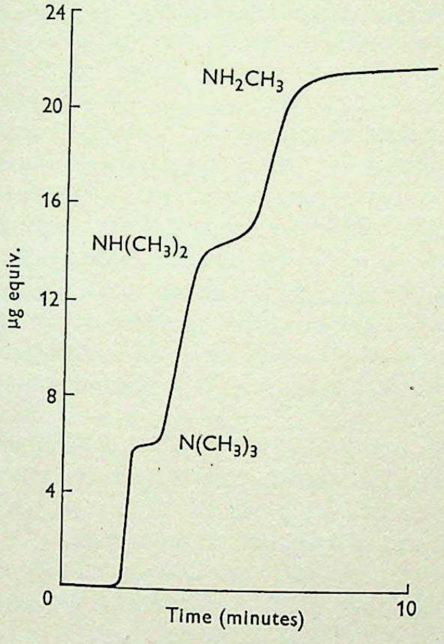


FIGURE 3 – *Separation of fourteen fatty acids ranging in chain length from C_2 to C_{11}; at the first arrow the time scale was shortened; at the time indicated by the second arrow the rate of flow of nitrogen was increased.* (a) *Acetic acid,* (b) *propionic acid,* (c) iso*butyric acid,* (d) n-*butyric acid,* (e) iso*valeric acid,* (f) *α-methylbutyric acid,* (g) n-*valeric acid,* (h) *γ-methylvaleric acid,* (i) *hexanoic acid,* (j) *heptanoic acid,* (k) *octanoic acid,* (l) *nonanoic acid,* (m) *decanoic acid,* (n) *hendecanoic acid.*



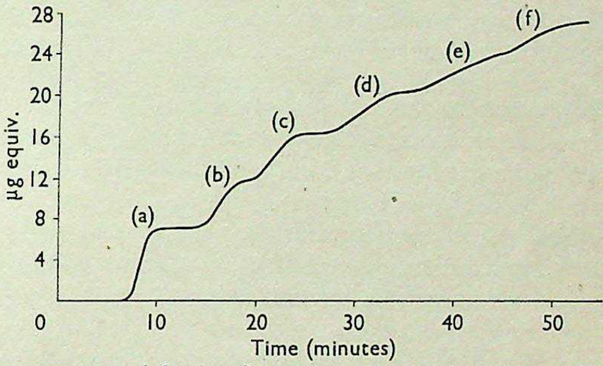


FIGURE 5 (*above*) – *Separation of aromatic amines, using automatic titration in glacial acetic acid for their detection. Column temperature 137° C; stationary-phase liquid paraffin.* (a) *Aniline,* (b) *methylaniline,* (c) *dimethylaniline,* (d) m-4-*xylidine,* (e) *dimethyl*-o-*toluidine,* (f) *diethylaniline.*

FIGURE 4 (*left*) – *Separation of mono-, di-, and tri-methylamines as recorded by the automatic burette. Column temperature 78·6° C; stationary phase glycerol.*

minimum of fatigue. The columns are easily and quickly packed and can be used many hundreds of times before exhaustion, this occurring only by stripping of the stationary phase. Results are highly reproducible; provided temperature and nitrogen flow are kept constant, a given substance will always emerge at the same time.

SOME APPLICATIONS OF THE TECHNIQUE

The introduction of a new separation technique invariably results in the discovery of substances previously undetectable: compare, for example, the discovery of new amino acids, nucleotides, purine bases, etc., by the use of paper and ion-exchange chromatography. Gas-liquid chromatography has proved to be no exception. For example, a study of naturally occurring fatty acids by the author has shown the presence of not only the odd-number fatty acids, the existence of which was long questioned (see also the work of Shorland and his co-workers [14]), but also odd-number unsaturated acids and at least two types of branched-chain fatty acids. These acids occur in significant amounts in sources as widely different as human sebum [15] and goat milk fat [16]. In biological research the high sensitivity of the technique makes it ideal not only for elucidation of the structures of new compounds but also for studying their metabolism.

The elucidation of the structure of reaction by-products, or of substances of biological origin obtainable only in small amount, is difficult by conventional chemical methods. Where chemical degradation can give rise to volatile fragments, the

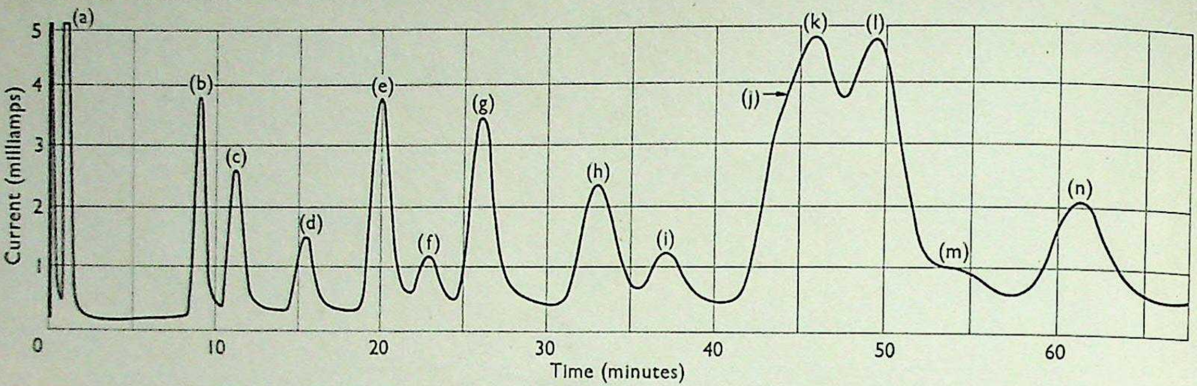


FIGURE 6 – *Separation of isomeric aliphatic hydrocarbons, using gas-density measurement to identify the zones leaving the column. The ordinate represents the reading of the recording galvanometer in this figure and in figures 7 and 8.* (a) *Air peak,* (b) iso*pentane,* (c) n-*pentane,* (d) 2:2-*dimethylbutane,* (e) cyclo*pentane plus* 2-*methylpentane and* 2:3-*dimethylbutane,* (f) 3-*methylpentane,* (g) n-*hexane,* (h) *methyl*cyclo*pentane,* 2:2-*dimethylpentane,* 2:4-*dimethylpentane,* (i) 2:2:3-*trimethylbutane,* (j) 3:3-*dimethylpentane,* (k) 2-*methylhexane,* (l) cyclo*hexane plus* 2:3-*dimethylpentane and* 3-*methylhexane,* (m) 3-*ethylpentane,* (n) n-*hexane.*

gas chromatogram can provide the necessary information as to their structure and quantity. For example, the nature of the side-chains attached to the 4-hydroxyquinoline-N-oxide nucleus of a naturally occurring streptomycin antagonist was established by running through a column oxidation products derived from only 10 mg of the impure substance [17].

In physicochemical studies the gas chromatogram can provide information on latent heats of evaporation, free energies of solution, and so on, and on the effect on such parameters of small changes in structure. The highly purified substances required for conventional techniques are not necessary, since the impurities can usually be removed in the course of the measurement.

The high resolving power of the technique has frequently had the result of demonstrating the impurity of substances formerly thought pure (figure 7) and has obvious uses in the examination of volatile intermediates for synthetic work. The consequent simplicity of determining the purity of chemicals supplied for laboratory use is likely to make organic chemists much more critical of the quality of commercially supplied reagents.

For routine examination of the composition of feed stocks and volatile commercial intermediates and final products, gas-liquid chromatography has no equal. Its ability to deal with complex mixtures has advantages over even the mass spectrometer, since when applied to mixtures the latter produces results in a form requiring great mathematical ingenuity for their understanding; the method should not, however, be considered as a rival to either the mass spectrometer or light-absorption techniques, since both these can give more useful information, when dealing with single substances, than the gas chromatogram can. The apparatus can be made robust enough for plant use, and the long life of the columns and the reproducibility of results make it suitable for operation by workers with relatively little training in its use.

FACTORS GOVERNING COLUMN EFFICIENCY

The main factors effecting column efficiency are rate of flow of gas, evenness of column packing, temperature, and nature of the stationary phase. Secondary factors such as the dead volume of the detector and the method of loading the columns will not be dealt with here (see [9]).

The rate of diffusion of the vapours in the stationary phase of the column seems to be the controlling factor in efficiency. Measurement of the

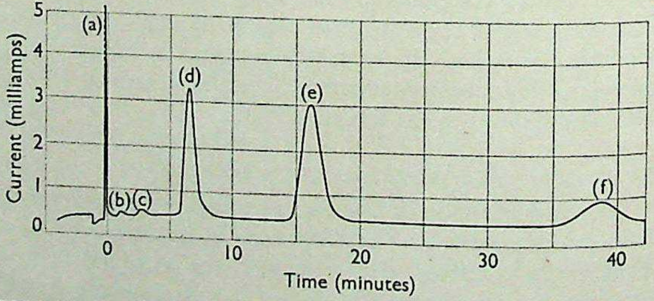


FIGURE 7 – *Analysis of a commercial sample of methyl myristate. Column temperature 197° C; stationary phase Apiezon M vacuum stopcock grease.* (a) *Air peak,* (b) *methyl* n-*octanoate,* (c) *methyl* n-*decanoate,* (d) *methyl* n-*dodecanoate,* (e) *methyl* n-*tetradecanoate,* (f) *methyl* n-*hexadecanoate.*

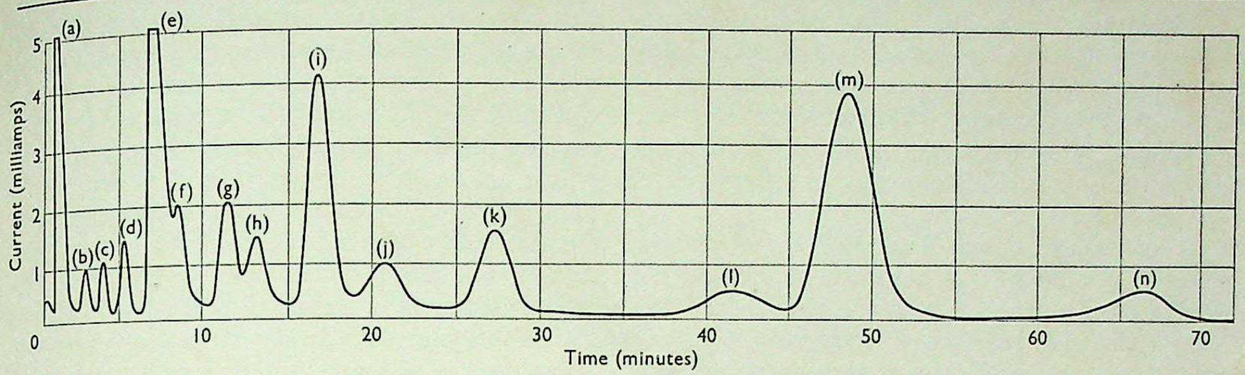


FIGURE 8 – *Separation of methyl esters of a variety of straight- and branched-chain fatty acids. Column temperature 197° C; stationary phase a high-boiling lubricating-oil extract.* (a) *Air peak,* (b) *methyl* n-*pentanoate,* (c) *methyl* n-*hexanoate,* (d) *anti*-iso*heptanoate,* (e) *methyl* iso*octanoate,* (f) *methyl* n-*octanoate,* (g) *methyl anti*-iso*nonanoate,* (h) *methyl* n-*nonanoate,* (i) *methyl* iso*decanoate,* (j) *methyl* n-*decanoate,* (k) *methyl anti*-iso*undecanoate,* (l) *methyl* iso*dodecanoate,* (m) *methyl* n-*dodecanoate,* (n) *methyl anti*-iso*tridecanoate.*

band-width of a series of zones shows the efficiency to increase with time of emergence from the columns. Clearly, increasing the flow-rate of nitrogen decreases the time of contact with the stationary phase and so decreases the efficiency. For the greatest efficiency columns are run as slowly as circumstances permit.

Highly viscous stationary phases, with their attendant slow diffusion rates, will give relatively inefficient columns, so that there is an advantage in using as mobile a stationary phase as is compatible with the need for low volatility at the operating temperature. Increase of column temperature increases column efficiency, owing to the increase in the diffusion rates in the liquid phase, but decreases separation factors.

CHEMICAL STRUCTURE AND CHROMATOGRAPHIC BEHAVIOUR

The interpretation of the behaviour of different substances in liquid-solid and liquid-liquid chromatograms is rendered difficult by interactions between the two phases. With the gas-liquid chromatogram, however, these are relatively minor effects, and in many cases it is possible to ascribe relative movements down the columns to differences in solute-solvent interaction.

In columns with stationary phases consisting of paraffin hydrocarbons the solute-solvent interaction is of the Van der Waals type only, and depends on the number, nature, and configuration of the atoms in the molecule. This is demonstrated in figure 9, which shows the relationship between molecular weight and configuration and the logarithm of the time of emergence from the column (for convenience measured relative to a standard substance) for a variety of saturated hydrocarbons; the stationary phase consisted of *n*-octadecane at 65° C. For a homologous series a linear relationship exists between the logarithm of the time of emergence and the chain length, since increasing the chain length by one $—CH_2—$ group increases the free energy of solution by a constant amount

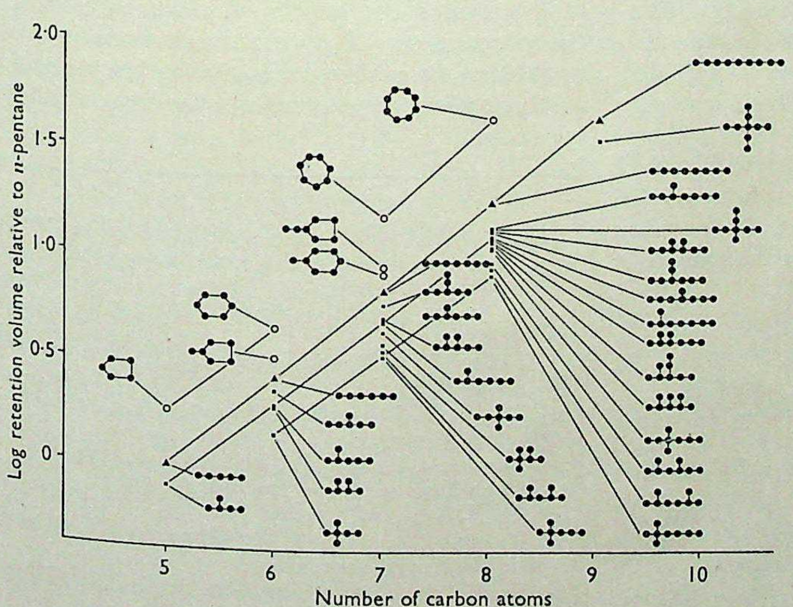


FIGURE 9 – *Relationship between structure and rate of movement down the column (relative to* n-*pentane) of a variety of saturated hydrocarbons. Column temperature 65° C; stationary phase* n-octadecane.

(approximately 750 cal/g mole under these conditions). This linear relationship conveniently allows the time of emergence of any member in a series to be calculated from knowledge of the behaviour of two or three members. It is also a great aid in the identification of substances of unknown structure.

It should be noted that closeness of boiling point is not reliable as a means of judging the feasibility of a given separation, since interaction forces in a pure liquid are not necessarily the same as those occurring in the stationary phase of a column. With substances of similar chemical structure, such as isomeric saturated hydrocarbons, closeness of boiling point does indicate that the substances will run close together in the gas chromatograms (see figure 9). Substances of identical boiling point but different chemical structure are, however, much easier to separate, since a stationary phase can often be chosen which has a greater energy of interaction with one component than with the other.

In stationary phases other than paraffin hydrocarbons, different forces come into play due to the interaction of polar groupings. For example, a polyether with the repeating unit $—CH_2CH_2—O—$ will show hydrogen bonding with substances possessing an active hydrogen atom, such as chloroform, primary and secondary amines, alcohols, phenols, etc.; with substances containing none of these groups, however, only the weaker Van der Waals forces will be involved. Aromatic hydrocarbons show strong interactions with molecules containing the groups $—NH_2$, $—OH$, $—COCH_3$, $—CN$, $—NO_2$, the interaction energy increasing in the order shown.

For a given separation the question to be asked is what the differences are in structure between the substances involved. Differences in the number and nature of alkyl groups would indicate that separation will be based on differences in Van der Waals interactions, requiring a fatty stationary phase. Possession of groups of different polarity will indicate the need for a stationary phase capable of interacting with such groups.

It is not necessary to maintain the column at a temperature comparable to the boiling point of the materials under examination, since many substances will move reasonably rapidly down the column when these partial pressures are of only a few millimetres. It is always advantageous to run the column at as low a temperature as possible in order to obtain large separation factors. For example, the $—CH_2—$ separation factor (the time of emergence of a substance relative to the time of emergence of the next lowest homologue) in stationary phases consisting of paraffin is 3·5 at 23° C but only 1·56 at 200° C.

Mixed stationary phases may be used so that the relative contribution of Van der Waals and polar solution forces are different from those produced in either pure solvent. In this way it is possible to make the stationary phase specifically hold back one component of a mixture. This additional degree of freedom makes available many more stationary phases than was previously thought possible.

Most of the work so far reported has been devoted to analytical problems, but the technique can also be used for the preparation of pure substances in quantities of 50–100 g. J. C. Tatlow [10] has used the gas-liquid chromatogram for the preparation of pure fluorocarbons in 10 g quantities; no other purification technique could produce pure compounds from the crude reaction products.

ACKNOWLEDGMENT

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REFERENCES

[1] JAMES, A. T. and MARTIN, A. J. P. *Biochem. J.*, **50**, 679, 1952.

[2] JAMES, D. H. and PHILLIPS, C. S. G. *J. sci. Instrum.*, **29**, 262, 1952.

[3] JANAK, J. *Coll. Czech. Chem. Comm.*, **19**, [5], 917, 1954.

[4] LITTLEWOOD, A. B., PHILLIPS, C. S. G., and PRICE, D. T. *J. chem. Soc.*, 1480, 1955.

[5] RAY, N. H. *J. appl. Chem.*, **4**, 21, 1954.

[6] *Idem. Ibid.*, **4**, 82, 1954.

[7] CLAESSON, S. *Ark. Kemi Min. Geol.*, **23A**, No 1, 1946.

[8] MARTIN, A. J. P. and JAMES, A. T. To be published.

[9] POLLARD, F. H. and HARDY, C. J. *Chem. and Ind.*, 1145, 1955.

[10] EVANS, D. E. M. and TATLOW, J. C. *J. chem. Soc.*, 1184, 1955.

[11] JAMES, A. T. *Brit. med. Bull.*, **10**, 170, 1954.

[12] *Idem. Chem. and Process Eng.*, **36**, 95, 1955.

[13] *Idem. Research*, **8**, 8, 1955.

[14] HANSEN, R. P. and McINNES, A. G. *Nature, Lond.*, **173**, 1093, 1954.

[15] JAMES, A. T. and WHEATLEY, V. R. To be published.

[16] JAMES, A. T. and MARTIN, A. J. P. *Biochem. J.* In press.

[17] CORNFORTH, J. and JAMES, A. T. *Ibid.* In press.

Sea-urchin spermatozoa

LORD ROTHSCHILD

The investigation of a biological phenomenon usually starts with a study of its morphology. This article is mainly concerned with the morphology of sea-urchin spermatozoa up to the time of fertilization, a subject which has lately been greatly facilitated by electron microscopy. Now that we can cut sections as thin as 250 Ångströms, structures can be seen whose existence was previously unknown. In addition, inferences can be made about the functions of these structures from other information about the biological phenomena under investigation.

Fertilization has been more intensively studied in sea-urchins than in any other animal or plant, for the following reasons:

1. Sea-urchin eggs and spermatozoa can be obtained in astronomical numbers. Some idea of the number of spermatozoa produced by a sea-urchin may be obtained from figure 4, which is a photograph of the common British sea-urchin, *Echinus esculentus*, spawning under water. The streams of semen being ejected from the five genital apertures are about 4½ cm long and contain some 100 000 000 spermatozoa. One sea-urchin can produce 1000 cm of semen during one breeding season.
2. Sea-urchin eggs are transparent, and therefore ideal material in which to observe under the microscope what happens when the sperm enters the egg.
3. Fertilization is easy to achieve *in vitro*.

Examination of a live or stained sea-urchin spermatozoon under the light microscope reveals that it consists of a pear-shaped head some 3½ μ long and 1 μ wide at its base, a globular mid-piece, and a vibratile tail which is about 0·2 μ in width and 50 μ long. Figure 1 is a reproduction of drawings published by the great microscopist G. Retzius in 1910 [11]. Apart from additional observations made possible by the electron microscope and those of G. T. Popa [10], who appeared to be blessed with second, though somewhat erratic, sight, Retzius's drawings might have been done in 1956 and not in 1910. The small refractile structures which can be seen at the tips of the heads in figure 1 do exist, though they are invisible in the living spermatozoon, even with the highest phase-contrast magnification.

THE TAIL AND ITS MOVEMENT

Sea-urchin spermatozoa swim by propagating S-shaped deformations, or waves of bending, along their tails, in an antero-posterior direction. The frequency of propagation is 30–40 waves per second. The remarkable photomicrograph reproduced in figure 9(*a*), which was taken by Sir James Gray of Cambridge University and M. M. Swann of Edinburgh University, shows these spermatozoa swimming in sea water. If sea-urchin spermatozoa are photographed using dark ground illumination, as in figure 9, the heads appear as brilliant patches of light on a dark background. The exposure time for figure 9(*a*) was 1/500th second, which explains why the deformations in the sperm tails are 'frozen' in position. If, however, the exposure is ½-second, the resultant picture is very different (figure 9(*b*)). In this photograph, spermatozoa are 'peeling off' from a drop of semen into sea-water, and the lengths of the white lines or tracks show how far the heads of the spermatozoa moved during the ½-second exposure. J. Gray [8] has shown that the sperm head tracks obtained in these circumstances are not spiral, although they look as if they are, but loops in a single plane. The looped tracks are caused by the peculiar movements of the sperm head (figure 2), which, at certain moments in each cycle, may actually go backward, even though the spermatozoon as a whole moves forward, relative to the ground.

Among the many questions which automatically come to mind when studying spermatozoa, one of the most important and interesting concerns the mechanism of their movements. Although the hydrodynamics of sperm movement are reasonably well understood, through the work of Gray [7, 8] and G. I. Taylor [15, 16], there is virtually no information about the changes within the tail responsible for the observed waves of bending. The first move in tackling this question is to investigate the morphology of the sperm tail. It is only in recent years that this has become possible, because the structures within the tail of a spermatozoon are too small to be seen with the light

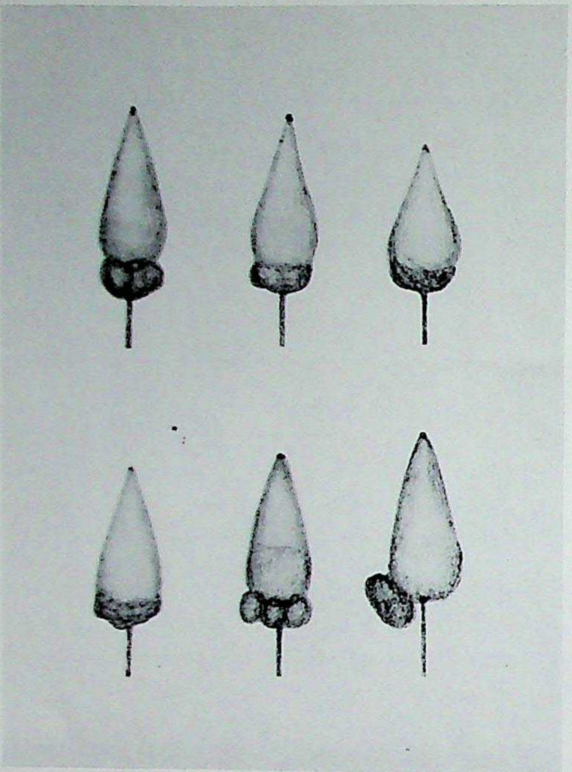


FIGURE 1 – *Drawings of spermatozoa of a sea-urchin* (Echinus esculentus), *by Retzius* [11].

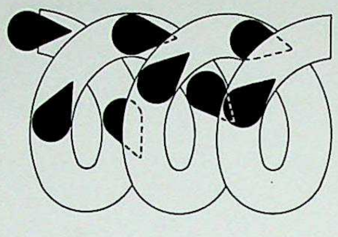


FIGURE 2 – *Diagram showing the movements of the head of a spermatozoon of a sea-urchin* (Psammechinus miliaris), *and the track formed by these movements when a swimming spermatozoon is photographed using dark ground illumination and a long exposure time, as in figure* 9(*b*). *Only some of the head positions have been included. After Gray* [8].

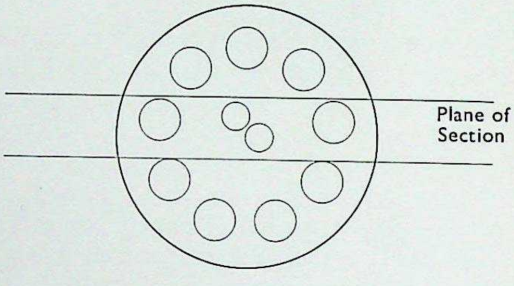


FIGURE 3 – *Diagram showing the plane of the section* (*at right angles to the plane of the paper*) *of the electron micrograph reproduced in figure* 6.

microscope. It seems to be a general rule, both in the animal and plant kingdoms, that vibratile protoplasmic structures, such as cilia and flagella, consist of nine fibrils in a circular array, embedded in an approximately cylindrical protoplasmic matrix, with two smaller fibrils running along the longitudinal axis of the cylinder. J. R. G. Bradfield [2] was the first to show that the sea-urchin sperm tail conforms to this ubiquitous pattern. Whether the nine fibrils, which are about 300 Ångströms in diameter, or the two central ones, which are about 250 Ångströms in diameter, are solid or tubular is a matter about which there is no certainty. Moreover, in an electron micrograph of a transverse section of the tail of a sea-urchin spermatozoon published by B. A. Afzelius [1], it appears that the two central fibrils are single, but that eight of the nine outer ones are double and the remaining one triple, which means that there are in reality nineteen fibrils in the outer ring, in nine groups. The chances of obtaining a reasonable length of the tail in longitudinal section are, for obvious reasons, remote. The electron micrograph reproduced in figure 6, of an approximately longitudinal section of part of a sea-urchin spermatozoon, shows that, at any rate in the neighbourhood of the head, there is no evidence of either the outer or central fibrils being twisted or helically disposed along the tail axis. But if the tail fibrils were twisted in such a way that one complete turn occupied the length of one tail wave, i.e. about 30 μ (figure 9(*a*)), there would be no chance of observing any twist in the short length of tail available for study in figure 6. This question is important when considering the mechanism of sperm movement.

There is a dark line running down the middle of what looks like one central tail fibril in figure 6. This line is almost certainly due to the plane of the section being such that the two central fibrils overlap along this line, as shown in figure 3.

The transverse section of a tail, with a white ring round it in figure 6, contains only two fibrils. This section was probably located near the extreme end of the sperm tail. According to Afzelius [1], some sections at the extreme end of the tail contain no filaments at all.

The most reasonable hypothesis to explain the waves of bending which pass along the tail of a swimming spermatozoon is that elements in the

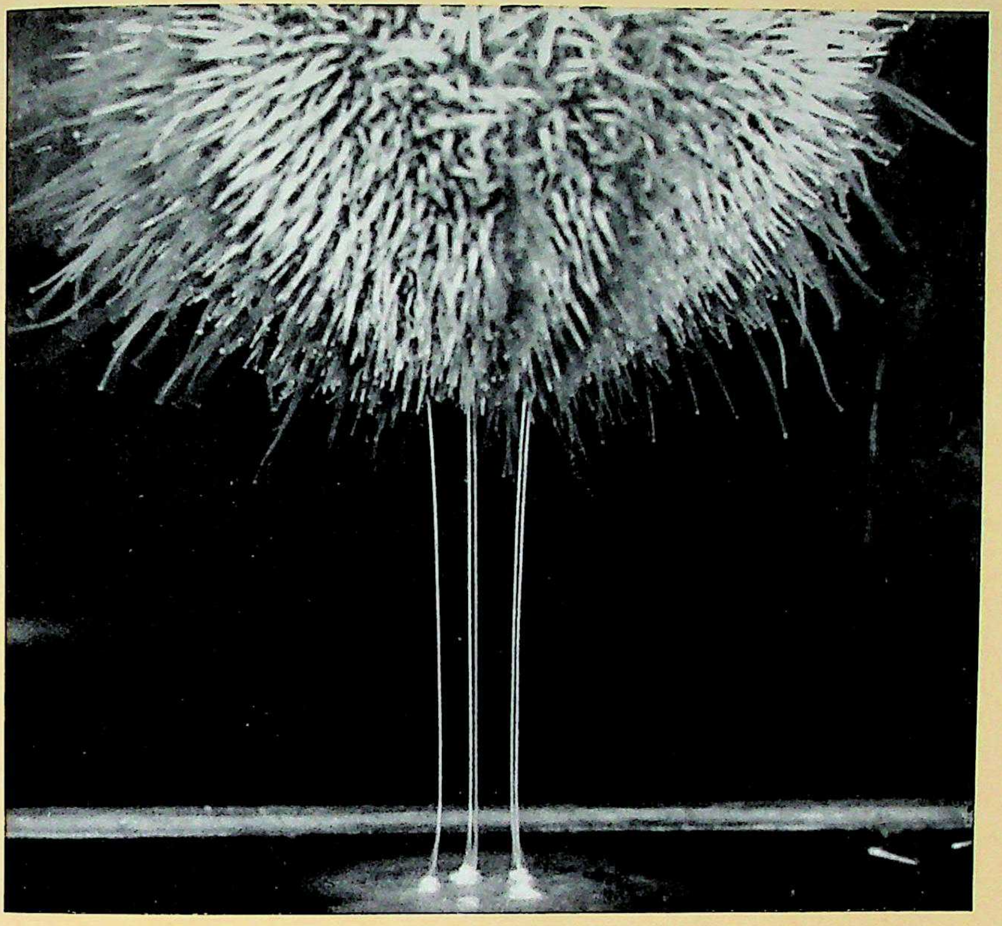


FIGURE 4 – *A male sea-urchin* (Echinus esculentus) *spawning under water.* (*Natural size.*)

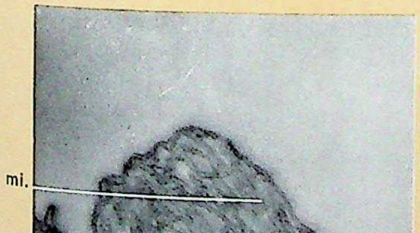


FIGURE 5 – (*a*) *Transverse section of the middle-piece of spermatozoon of a sea-urchin* (Echinus esculentus). *The section is in the neighbourhood of the centriole. Note that the two central fibrils are absent. Fixed with osmium tetroxide. t.f., outer ring of tail fibrils; mi., mitochondria.*

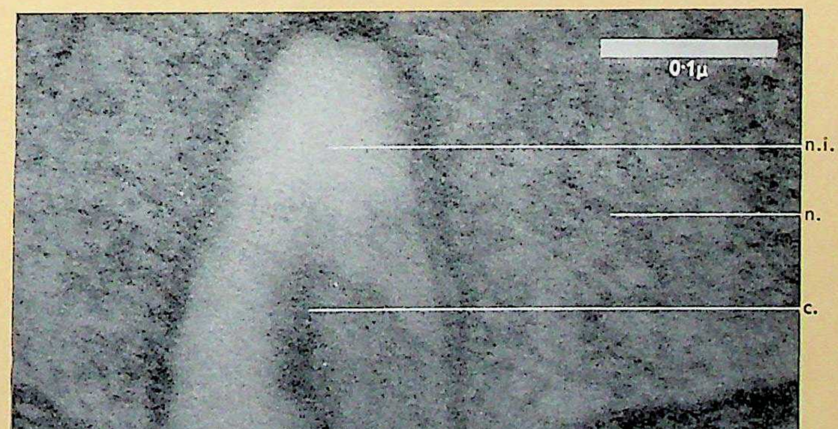


FIGURE 5 – (*b*) *Longitudinal section of the posterior end of the head of spermatozoon of a sea-urchin* (Echinus esculentus). *The electron micrograph shows the nuclear invagination (n.i.) which normally contains the centriole (c), part of which is visible. Note mitochondria (mi.) in the middle-piece (m.) bottom right. n., nucleus. Fixed with osmium tetroxide.*

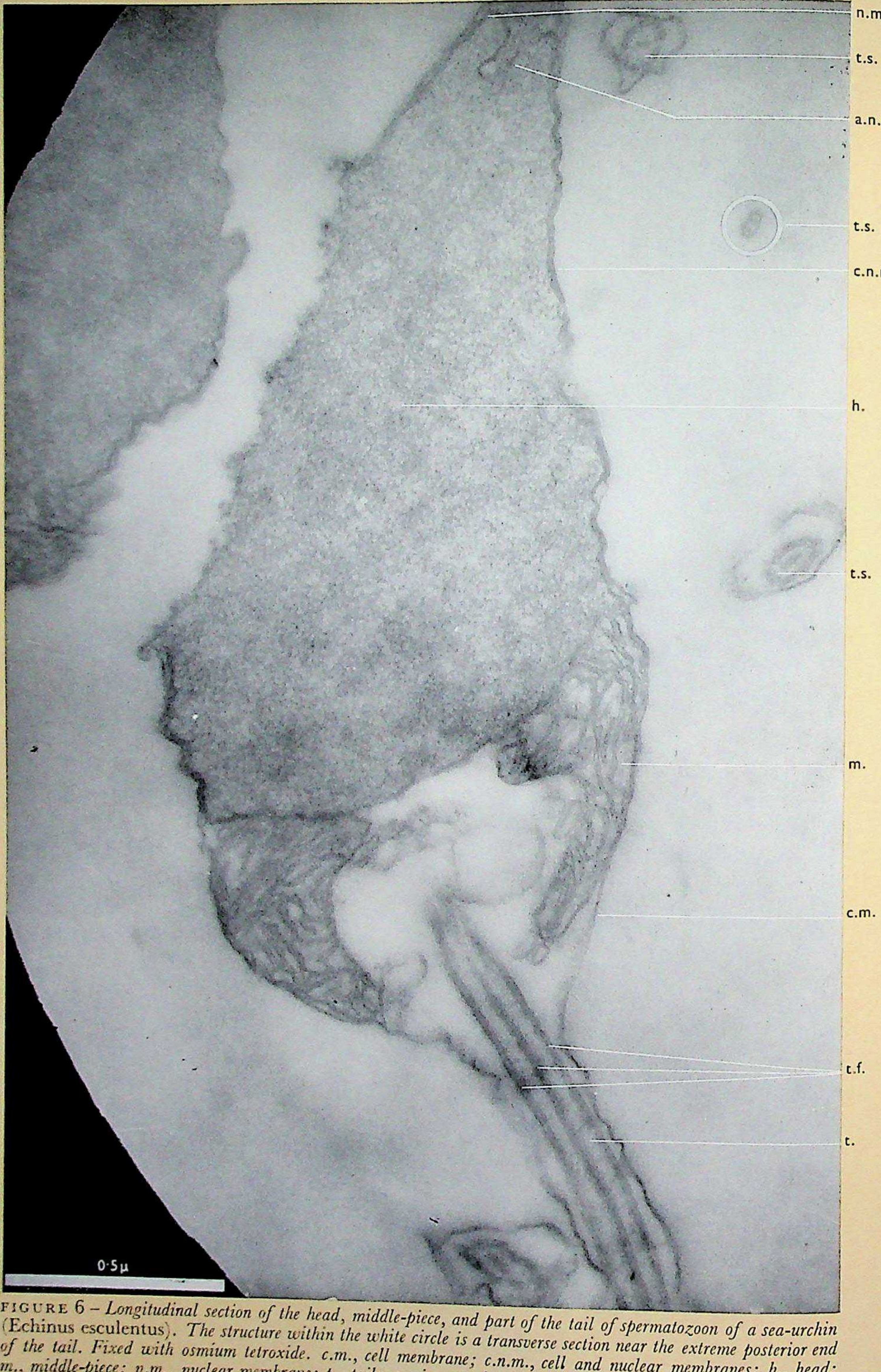


FIGURE 6 – *Longitudinal section of the head, middle-piece, and part of the tail of spermatozoon of a sea-urchin* (Echinus esculentus). *The structure within the white circle is a transverse section near the extreme posterior end of the tail. Fixed with osmium tetroxide. c.m., cell membrane; c.n.m., cell and nuclear membranes; h., head; m., middle-piece; n.m., nuclear membrane; t., tail; a.n.i., anterior nuclear invagination; t.f., tail fibrils; t.s., transverse sections of tail. The upper* [illegible] *were cut at the posterior end of the middle-piece.*

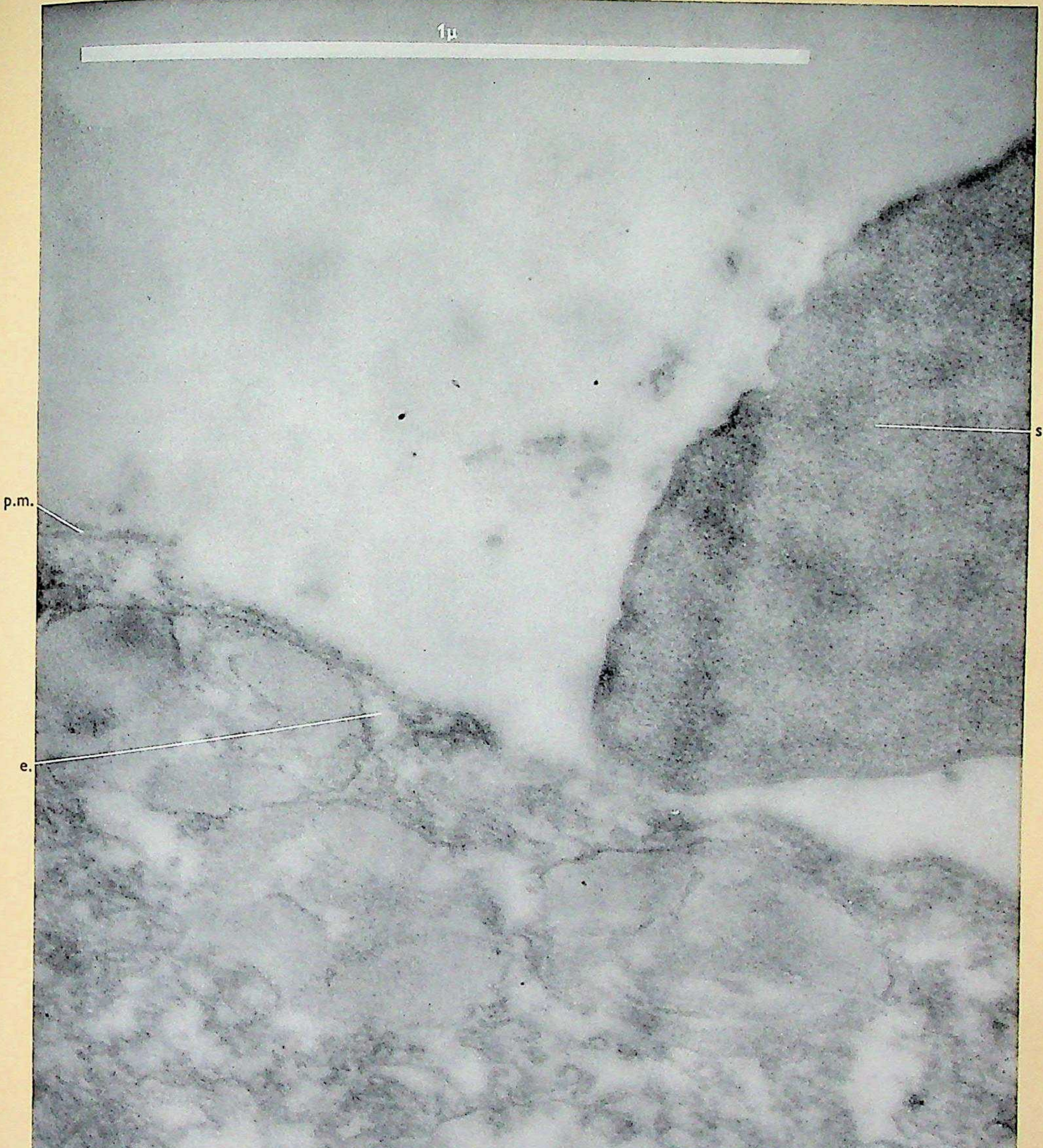


FIGURE 7 – *Spermatozoon of* Echinus esculentus *on or very near the surface of an egg of the same species. Fixed with osmium tetroxide* 25 *seconds after mixing unfertilized eggs and spermatozoa. Note apparent disappearance of plasma membrane (?) in the neighbourhood of the anterior end of the spermatozoon. e., egg; s., spermatozoon (head); p.m., plasma membrane (?).*

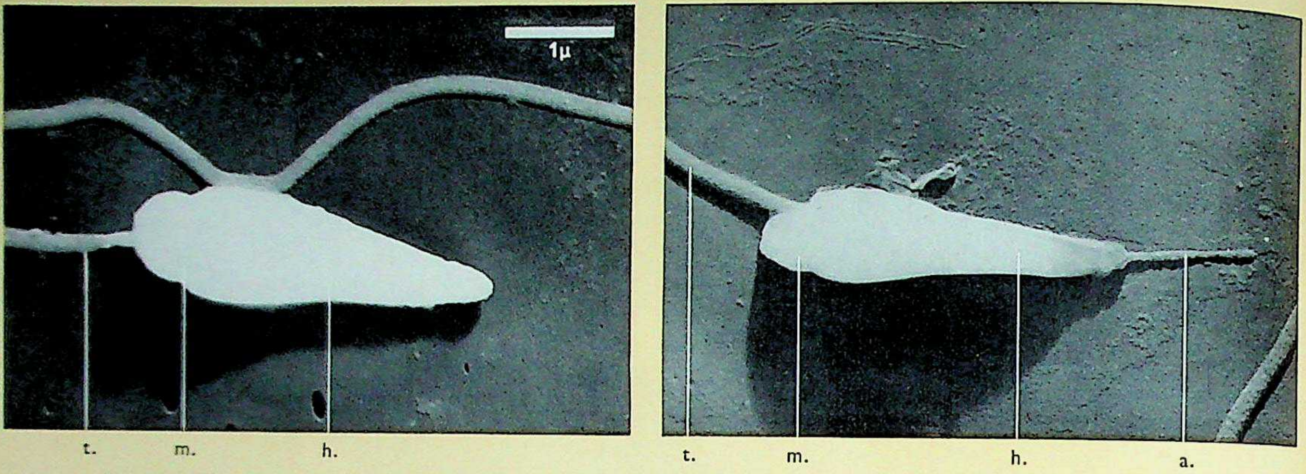
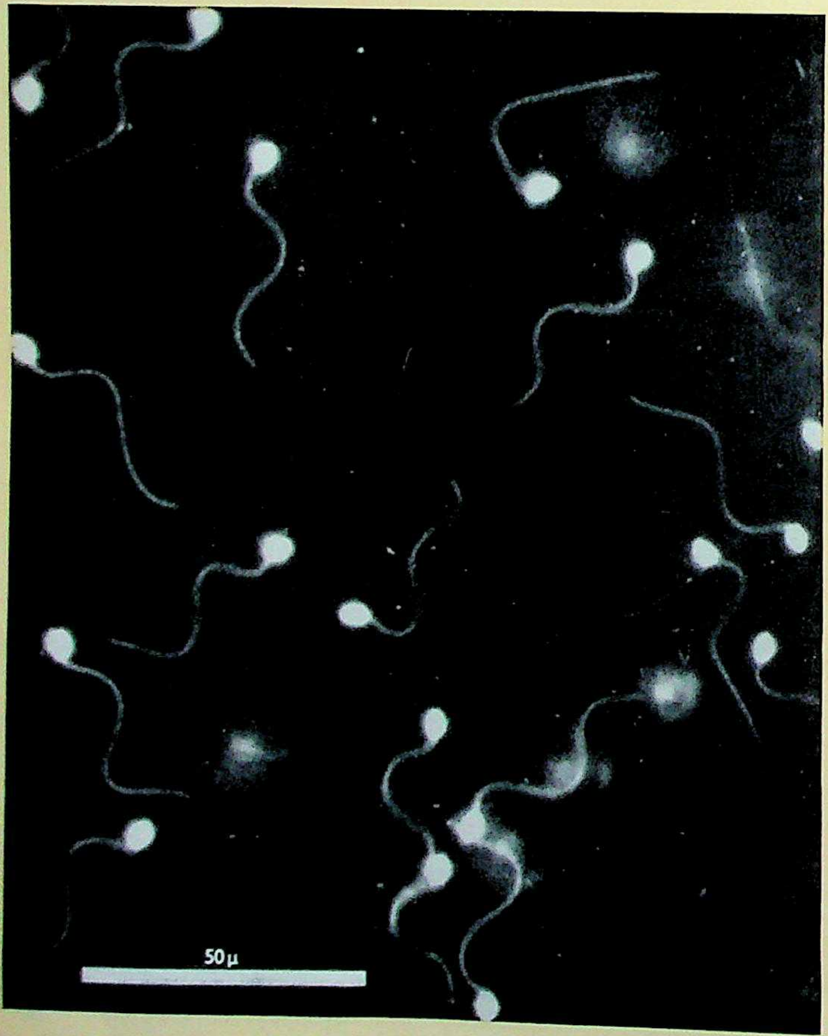


FIGURE 8 – (*left*) *Spermatozoon of a Japanese sea-urchin* (Hemicentrotus pulcherrimus) *in sea-water. The semen was diluted with sea-water and the suspension fixed with formalin* 1½ *minutes later* (*J. C. Dan* [4]). *h., head; m., middle-piece; t., tail.* (*right*) *Spermatozoon of* Hemicentrotus pulcherrimus. *The semen was mixed with sea-water and egg secretions were added one minute later. This caused agglutination of the spermatozoa and the 'extrusion' of the acrosomal filament. Reversal of agglutination occurred* 3½ *minutes later, and after* 4 *minutes the suspension was fixed with formalin* (*Dan* [5]). *a., acrosomal filament; h., head; m., middle-piece; t., tail.*



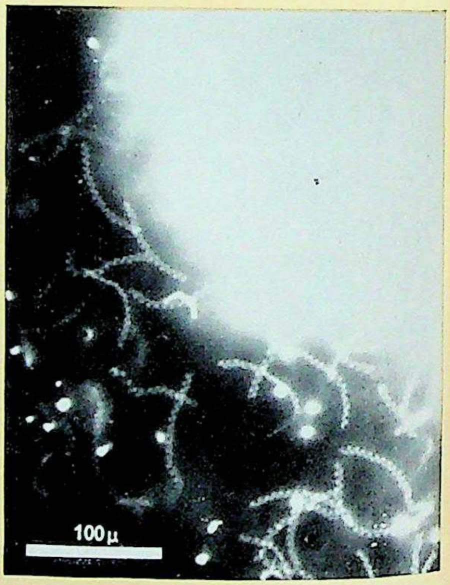


FIGURE 9 – (*a*) (*left*) *Spermatozoa of a sea-urchin* (Psammechinus miliaris) *swimming in sea-water. Photomicrograph by J. Gray and M. M. Swann. Exposure time,* 1/500*th sec.; dark ground illumination.* (*b*) (*above*) *Semen of sea-urchin* (Psammechinus miliaris) *in sea-water at* 17°. *At the edge of the white drop of semen, spermatozoa are 'peeling off' into the water. The apparently spiral tracks are caused by the translatory movements of the sperm heads during a photomicrographic exposure of* 0·5 *seconds. Dark ground illumination.* (*Rothschild and Swann* [12]).

nine outer fibrils shorten periodically in a particular order [8]. If elements in the tail execute active bending (which involves their contraction), there must also be other structures in the tail which resist compression. The compression-resisting structures might be the protoplasmic matrix in which the fibrils are embedded, or the tail membrane, or the two central fibrils. From Gray's analysis of the movements of sea-urchin spermatozoa it appears probable that the nine outer fibrils are capable of active contraction. But if they run straight along the whole length of the sperm tail, complicated machinery analogous to a nervous control mechanism must exist to ensure that the fibrils contract in the right order and at the right time at different points along their long axes. Less complicated machinery is required if the fibrils are twisted, because, in these circumstances, each fibril need only contract as a whole, in a particular order, to achieve waves of bending. Bradfield [3] has raised the possibility that the two central fibrils, which are chemically different from the nine outer ones [9], may be responsible for the conduction of 'nerve impulses' along a cilium. As mentioned earlier, the amount of twist required to obviate the need for this sort of machinery is so slight as to be difficult to observe. In the absence of more information, the simpler hypothesis, involving twisted fibrils, should therefore not be ignored, at any rate so far as the tails of spermatozoa are concerned.

The tail of the sea-urchin spermatozoon passes through the mid-piece and terminates in an invagination of the posterior part of the nucleus that can be seen in figure 5(*b*) but not in figure 6, in which the plane of the section is not sufficiently central to reveal the cavity. The tail became detached during preparation of the section shown in figure 5(*b*). The anterior end of the tail terminates in the centriole, which, according to Afzelius [1], is a 'curved disk', with a diameter of 0·15 μ. Afzelius says that the nine outer fibrils can be identified at the edge or margin of the centriole, while the two central fibrils arise in the middle of it. In several transverse sections cut in the region of the centriole I have, however, noticed that the two central fibrils are missing (figure 5(*a*)). Although this may have been due to some accident during preparation of the sections, the same thing has been observed at the anterior ends of cilia [6], and it therefore seems probable that Afzelius's view that the central fibrils extend into the centriole is based on misinterpretation of his electron micrographs.

The centriole is, presumably, the structure from which orders are sent out to the fibrils to contract. We have no idea whether these orders are chemical or electrical, nor how they are sent out, and it will be some time before any experimental techniques will be available to investigate this question. Bradfield [3] has published a speculation about this subject, but the complexity of his model is in part due to his belief, which is shared by Afzelius, that there is no possibility of the nine outer fibrils being helically disposed along the sperm tail (or the long axis of a cilium).

MID-PIECE

This structure is seen in longitudinal section in figure 6 and in transverse section in figure 5(*a*). It is bounded by a double membrane, 100 Ångströms thick, and contains mitochondria of a very characteristic type. The mid-piece of a spermatozoon is believed to contain the enzyme systems and internal fuel supplies necessary for sperm movement, though there is little experimental evidence in support of this view. K. Cleland and I [13] tentatively came to the conclusion that the mid-pieces of sea-urchin spermatozoa which had exhausted their internal fuel supplies were smaller than those of fresh spermatozoa. We also found that the mid-piece contained quantities of lipid, a suggestive finding as sea-urchin spermatozoa metabolize phospholipid to provide energy for their movements. Apart from these fragmentary observations, little is known about the functions of the mid-piece, apart from inferences based on its mitochondria-like contents.

HEAD

The function of a spermatozoon is to stimulate the egg to develop and to provide the future embryo with genes of paternal origin. The latter function is discharged by the sperm nucleus, which constitutes the major part of the head. The nucleus is bounded by a double membrane, about 150 Ångströms thick, outside which there is another, somewhat thinner, membrane which covers the whole surface of the spermatozoon (figure 6).

When a spermatozoon fertilizes an egg, it first becomes attached to the egg surface and later penetrates into the inside of the egg. To do this it must pass through the plasma membrane, which is probably composed of lipids or lipoproteins. This membrane can be seen in figure 7, which shows a spermatozoon attached, or just about to become attached, to the surface of an egg. The dissolution of the plasma membrane at the point of attachment of the fertilizing spermatozoon is probably achieved by a substance which can be extracted from sea-urchin spermatozoa and is called Sperm Lysin (I), or Androgamone III (A. III). A. III haemolyses red blood cells and has an effect on the surface of sea-urchin eggs which is similar to that of bee venom and detergents [14]. It may be a long-chain unsaturated fatty acid. There was, until recently, little direct information about the location of A. III in sea-urchin spermatozoa, though for obvious reasons the most probable location is the front of the head. Figure 6 shows that the tip of the sperm head is morphologically differentiated from the rest of the head, which contains nuclear material. In electron micrographs published by Afzelius [1] there is a spherical structure, which is barely visible in figure 6, above the nuclear invagination. It is tempting to believe that A. III is located in this part of the sperm head, either in the spherical body or the invagination. The dissolution of the egg plasma membrane can be seen in figure 7, in the neighbourhood of the anterior end of the sperm head. To the right and left of this region the membrane is intact, while some substance appears to connect the sperm head with the broken down region of the egg surface. In the original electron micrograph this 'substance' is a spherical body, somewhat smaller in diameter than that reproduced by Afzelius. Although the section of the spermatozoon in figure 7 is somewhat oblique, so that the extreme tip of the head is above or below the plane of the section, one has to be rather lucky to arrest fertilization at the moment of attachment of the spermatozoon to the egg surface, find the egg in question, and then cut a section in the right plane. This is unfortunate, because it means that the examination of a number of eggs in precisely this condition, which would be desirable before making any generalizations, presents considerable difficulties.

In some species of sea-urchins, a filamentous process, sometimes called the acrosomal filament, is ejected from the tip of the sperm head when the spermatozoon comes into contact with water in which eggs have been standing. Figure 8 (left) shows what the spermatozoon of a Japanese sea-urchin, *Hemicentrotus pulcherrimus*, looks like when in normal sea-water. Figure 8 (right) is an electron micrograph of a spermatozoon of the same species which has been suspended in egg water, i.e. sea water in which eggs have been standing. Secretions from the unfertilized eggs into the sea water have catalysed the ejection of the acrosomal filament. The relationship between this filament and the structure at the tip of the sperm head in figure 6 is not clear. Does contact with egg water make the invaginated structure behave like the finger of a rubber glove which, having been pulled inside out when taking the glove off, is blown out the right way? More experiments are needed to resolve this question, but so far as the spermatozoa of *Echinus esculentus* are concerned, the existing evidence does not suggest that the invaginated structure is blown inside out when the spermatozoon comes in contact with the egg surface.

CONCLUSION

'Modern' biologists sometimes adopt a lofty attitude towards morphologists, making unfavourable comparisons between their work and that of biochemists and biophysicists. I hope that this article will help to dispose of the idea that morphology is a dull subject. It is as exciting today as in the seventeenth century, when Leeuwenhoek was studying the morphology of his spermatic animalcules.

ACKNOWLEDGMENTS

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REFERENCES

[1] AFZELIUS, B. A. *Z. Zellforsch.*, **42**, 134, 1955.
[2] BRADFIELD, J. R. G. *Quart. J. micr. Sci.*, N.S., **94**, 351, 1953.
[3] *Idem. Symp. Soc. exp. Biol.*, **9**, 306, 1955.
[4] DAN, J. C. *Biol. Bull., Wood's Hole*, **103**, 54, 1952.
[5] *Idem. Ibid.*, **107**, 335, 1954.
[6] FAWCETT, D. W. and PORTER, K. R. *J. Morph.*, **94**, 221, 1954.
[7] GRAY, J. *Quart. J. micr. Sci.*, N.S., **94**, 551, 1953.
[8] *Idem. J. exp. Biol.*, **32**, 775, 1955.
[9] HODGE, A. J. *Aust. J. sci. Res.*, B, **2**, 368, 1949.
[10] POPA, G. T. *Biol. Bull., Wood's Hole*, **52**, 238, 1927.
[11] RETZIUS, G. *Biol. Untersuch.*, N.F., **15**, 55, 1910.
[12] ROTHSCHILD, LORD and SWANN, M. M. *J. exp. Biol.*, **27**, 400, 1950.
[13] ROTHSCHILD, LORD and CLELAND, K. W. *Ibid.*, **29**, 66, 1952.
[14] RUNNSTRÖM, J., TISELIUS, A., and LINDVALL, S. *Ark. Zool.*, **36A**, No. 22, 1945.
[15] TAYLOR, SIR G. I. *Proc. roy. Soc.*, A, **209**, 447, 1951.
[16] *Idem. Ibid.*, **211**, 225, 1952.

The velocity of light

L. ESSEN

Probably no physical constant is of more fundamental importance in physical theory and practice than is the velocity of light, and this is reflected in the great effort which has been expended in its measurement. Apparent discrepancies between some of the earlier determinations suggested that the velocity of light is not strictly constant, but depends upon the time of the determination and the frequency of the radiation used. Analysis of the results of the most modern methods, however, gives no support to this suggestion.

The velocity of light was first measured, in 1676, by the astronomer Roemer, who correctly attributed the irregularities in the times of the eclipses of Jupiter's satellites to the time taken for the light to travel along the diameter of the Earth's orbit round the Sun. Another astronomical method, depending on the apparent shift of star positions with the Earth's motion, was used by Bradley, fifty years later, but it was not until 1849 that Fizeau obtained a value from observations of the time of travel of a pulse of light on the Earth's surface. In Fizeau's famous experiment the light was chopped by a toothed wheel rotating in front of the source, and reflected by a mirror at a distance of about 9 km. If the returning pulses of light passed through a gap between the teeth of the wheel a bright image was seen in a telescope behind it, but if they fell on a tooth the intensity of the image was a minimum. The speed of the wheel was adjusted to give this condition of minimum intensity, and the velocity was then calculated from the distance travelled, the rotational speed of the wheel, and the number of teeth.

During the latter half of the nineteenth century the value of the constant was required for the electrical calculations involved in problems such as the design of submarine cables, and many measurements were made by both electrical and optical methods. This connection between the velocity of light and electrical theory is so important that it is worth while recalling how it was established. The force between electric charges was found to depend on the permittivity ε of the medium and that between electric currents on the permeability μ, but so long as electrostatics and electromagnetics were treated as separate subjects it was not necessary to know the relationship between the two constants; by a suitable choice of unit, the values in a vacuum, ε_0 and μ_0, could both be made equal to unity. In electromagnetic problems, however, it is essential to know the ratio between quantities expressed in the two systems of units, and this ratio, in the case of electric charge for example, turns out to be $(\mu_0\varepsilon_0)^{-\frac{1}{2}}$, which has the dimensions of a velocity. The ratio was determined by measuring a charge in the two units and was found to be, within the experimental errors, equal to Fizeau's value for the velocity of light. Faraday, with his brilliant insight, had already suggested that light might be a manifestation of electromagnetic energy, and Maxwell formalized the idea in his famous electromagnetic theory of light, according to which the velocity of all electromagnetic waves *in vacuo* is $(\mu_0\varepsilon_0)^{-\frac{1}{2}}$ and is thus independent of the frequency of the waves. This conclusion was supported by all the results obtained. The most accurate electrical measurement, made by Rosa and Dorsey, gave a value of 299 784 ± 30 km/s. The most famous of the classical optical experiments, carried out by Michelson, Pease, and Pearson, using a light beam in an evacuated metal pipe a mile long, gave 299 774 ± 11 km/s.

In 1941 R. T. Birge [1] reviewed the experimental work, and concluded that the most probable value was 299 776 ± 4 km/s, and this value was generally believed to be sufficiently accurate for the new applications in nuclear physics, radar, and radio engineering which were then becoming of great importance. But to someone who, like the writer, had been engaged in precise electrical measurements, limits of ± 4 km/s seemed too optimistic in view of the large observational scatter of about ± 50 km/s. It was therefore decided to make a new determination, using an instrument known as a cavity resonator, which was developed during the last war for measuring the frequency of very short waves. It consists of a hollow metal cylinder, or waveguide, closed at both ends by metal plates, and electrically coupled to an oscillator and a detector through small holes in the walls. Electrical resonance occurs when the length of the cavity is $n\lambda_g/2$, λ_g being the wavelength of the radiation in the guide and n being an integer. This condition, which can be recognized by a sharp increase of the signal in the detector, can be established by varying either the frequency of the oscillator or the length of the cavity. The value of the instrument rests on the extreme sharpness of the resonance, which makes it possible to set the frequency or length with a precision of 1 part in 10^6 if suitable precautions are taken. It was this precision of setting which made the cavity resonator method appear particularly attractive in comparison to the optical method.

There is a simple relationship between the resonant frequency, the dimensions of the guide, and the quantity $(\mu_0\varepsilon_0)^{-\frac{1}{2}}$; the frequency can therefore be calculated if a value be assumed for $(\mu_0\varepsilon_0)^{-\frac{1}{2}}$ which can be taken as the velocity of light *in vacuo*. It is more convenient to calibrate the instrument by measuring, directly in terms of a frequency standard, the frequency of the oscillator corresponding to a particular setting; if the dimensions and the frequency are both measured, a value for the velocity is obtained.

The first determination by this method was made in 1946 at the National Physical Laboratory by L. Essen and A. C. Gordon-Smith [2], using the apparatus shown in figure 1. The cavity resonator was of the simplest possible geometrical construction, and was mounted in an evacuated enclosure so that the result need not be corrected for the refractive index of air. The frequency of the oscillator was varied slowly in the region of 3000 Mc/s (wavelength 10 cm) until resonance occurred, and a reading was obtained on the galvanometer scale. The frequency of the oscillator corresponding to the peak of the resonance was measured by reference to the standard, and the dimensions of the cavity were determined by careful metrological measurements. The repetition accuracy of this preliminary experiment was ± 1 km/s—about fifty times better than that of any previous determination—but there was evidence of small systematic errors. These were reduced [3] by using a form of resonator shown in figure 2. The length of the resonator was varied by moving a piston, and successive resonances were obtained at intervals of $\lambda_g/2$. The distance moved was measured by means of gauges placed between the end of the piston rod and a fixed base plate. The length for the first resonance is not exactly $\lambda_g/2$ because of end effects, but the true value is obtained from the difference between successive settings. Moreover, by making measurements at different frequencies—the values actually used were between 5000 Mc/s (6 cm) and 11 000 Mc/s (2·7 cm)—it was possible to eliminate both the diameter and the wall resistance from the calculations and to express the result entirely in terms of frequencies and lengths. This was a very important feature of the experiment, because it is very difficult to calculate the effects of the inevitable mechanical and electrical imperfections of the surfaces.

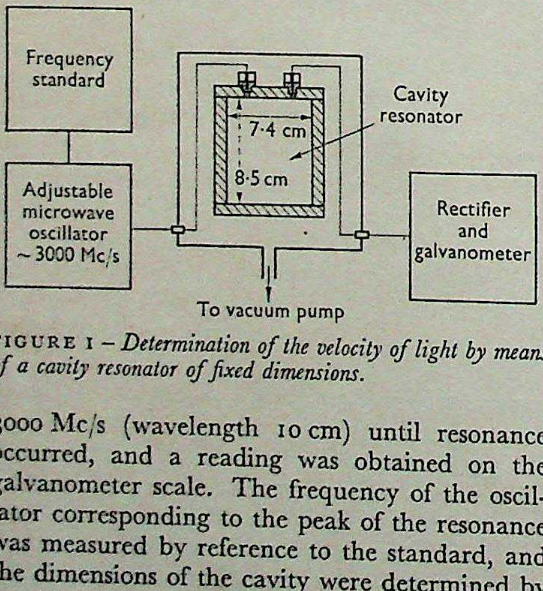
Frequency standard
Adjustable microwave oscillator ~3000 Mc/s
7·4 cm
8·5 cm
Cavity resonator
Rectifier and galvanometer
To vacuum pump

FIGURE 1 – *Determination of the velocity of light by means of a cavity resonator of fixed dimensions.*

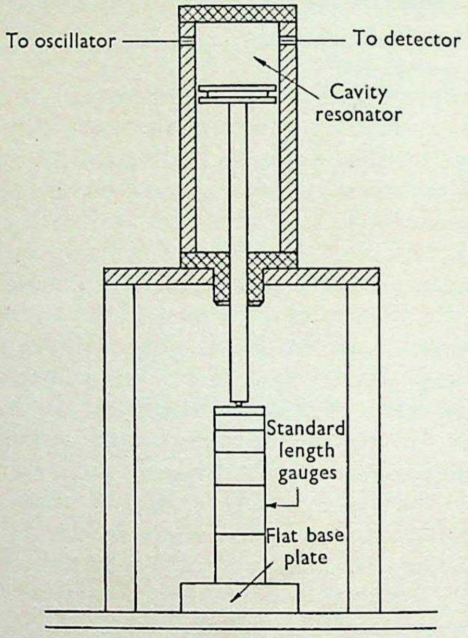

FIGURE 2 – *Cavity resonator of variable length.*

A further cavity resonator result obtained by K. Bol [4] at Stanford University is 3 km/s lower than that obtained at the National Physical Laboratory; this small discrepancy may be due to the fact that Bol was not able, with his form of cavity, to eliminate experimentally the effects of wall imperfections.

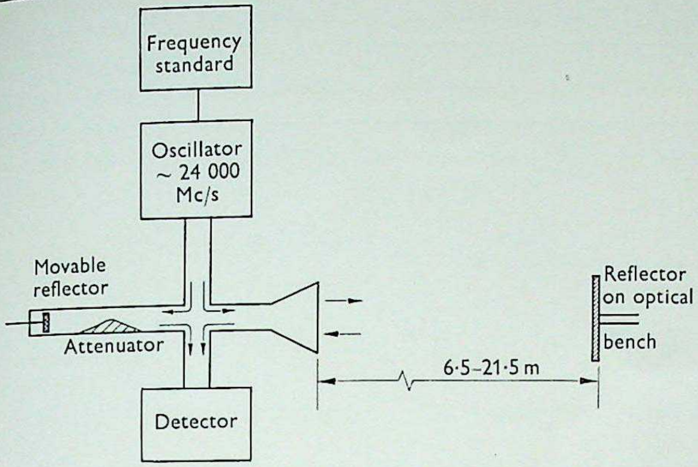

FIGURE 3 – *Determination of velocity of light by a Michelson type interferometer for radio waves.*

In more recent measurements at the National Physical Laboratory K. D. Froome [5] has made use of a microwave form of Michelson interferometer (figure 3). Radio waves approximately 1·25 cm long (24 000 Mc/s) travel down a waveguide to a junction, where they are split into two equal beams. One beam is radiated into the open air from a horn and a portion of it is returned from a distant reflector, through the horn to the junction, and thence to the detector. The other beam is contained within a waveguide network, and is reflected back to the junction and to the detector after being attenuated in its path by an amount equivalent to the attenuation of the beam in the open air. The two beams of equal strength are thus recombined at the detector, and the intensity of the signal depends on their relative phases. If the open air reflector is moved towards the horn the phase of the beam will cycle through 360° for each half-wavelength moved, and the detected signal will pass through maximum and minimum values. The distance moved can thus be expressed in terms of wavelengths of the radiation, and as the frequency also can be measured with great precision the velocity can be found ($c = \lambda f$). There are two important corrections to be applied, one due to the refractive index of air, and the other to the diffraction of the wave. The refractive index was measured by Essen and Froome [6] in a preliminary experiment with an accuracy of 1 part in 10^7, and the diffraction error, on the average about 16 km/s, was determined by a combination of theory and experiment. Froome expects [7] that a further measurement of this kind using shorter waves will give a value with a maximum error of at most $\pm$ 1 part in 10^6 ($\pm$ 0·3 km/s).

There has always been speculation, on rather inadequate evidence, about the variation of the velocity of light with time or with frequency. It is fortunate, therefore, that the recent results, nearly all of which differ by about 17 km/s from Birge's value, have been obtained by a number of completely different techniques using a wide range of frequencies. In addition to those already mentioned E. Bergstrand [8] has carried out several vastly improved optical measurements with an instrument, called a geodimeter, designed for surveying purposes. A parallel beam of light waves, modulated at a frequency of 10 Mc/s by a Kerr cell, is reflected back from a mirror about 10 km distant. The reflected wave is detected by a photomultiplier tube, the sensitivity of which is varied at the modulation frequency. The strength of the detected signal therefore depends on the phase of the returning wave and hence on the distance travelled. Two further features make the method a practical success. The beam is modulated by a 50 c/s square wave in such a way that for alternate half-cycles of 0·01 second duration the phase of the 10 Mc/s modulation is reversed. There are thus in effect, travelling in the same path, two beams, which are combined in opposition by the detector to give a sharp zero, instead of a flat minimum, when the distance travelled is a whole number of half-wavelengths of the modulation. The other feature is a short calibrated artificial path formed by multiple reflections between a set of prisms, and this enables the zero of the instrument to be found. It seems likely that the geodimeter will in some applications replace the familiar tape methods of establishing base lines, the distances being determined from the times of travel and velocity of pulses of light, the value for velocity being assumed. But in these initial experiments it has been used on well established geodetic base lines, the lengths of which are known, and has given accurate values for the velocity of the light waves. A geodimeter was lent by the United States to the British Ordnance Survey in 1953 for experimental checks on the Ridgeway and Caithness base lines, and the results obtained were in close agreement with the geodetic values [9]. As the instrument was previously calibrated at the National Physical Laboratory the measurements can be regarded as an independent measurement of velocity giving a result 0·8 km/s less than that obtained by Bergstrand.

An important series of determinations made by C. J. Aslakson [10] also employed a technique developed for surveying purposes, but operated over much greater distances. This is an adaptation of the Shoran radar system using frequencies near 300 Mc/s (wavelength 1 m). In normal use a pulse of radio waves transmitted from an aeroplane is returned from two ground stations, and the times taken are read from a time scale on the screen of a cathode-ray tube formed by time markers from a quartz oscillator. The distances of the plane from the two ground stations are computed from the times of travel and the velocity. In wartime practice the time scales were adjusted to read distance directly, on the assumption of the optical value of velocity (299 776 km/s, corrected for the refractive index of air), and the position of the plane was found from the two distances. In Aslakson's experiments the ground stations were situated at points whose distance apart, of the order of 100 miles, had been determined accurately by geodetic methods. The plane flew across the line joining them, and the minimum distances were determined. If the height of the plane is also known, the ground distance between the stations can be calculated, a comparison between the measured values then giving the error in the value of velocity assumed in the calibration of the distance scale. One of the main difficulties was the correction for the refractive index of air, which varies considerably over the path. However, Aslakson was finally able to obtain consistent results, and radar methods have now been used both in the United States [11] and in Canada [12] for large-scale surveying.

Results of recent determinations of the velocity of light (c_0)

Date	*Author*	*Method*	*Result (km/s)*	*Experimental scatter (km/s)*
1941	Birge	Discussion of results up to 1941	299 776 ± 4	About 100
1948	Essen and Gordon-Smith	Cavity resonator	299 792 ± 3	7 (including systematic effects)
1949	Bergstrand	Optical, Kerr cell geodimeter	299 796 ± 2	4·8 (between nightly means)
1949	Aslakson	Radar	299 792·4 ± 2·4	11
1950	Houstoun [14]	Optical, quartz plate	299 775 ± 9	180
1950	McKinley	Optical, quartz plate	299 780 ± 70	[1]
1950	Bergstrand	Optical, Kerr cell geodimeter	299 793·1 ± 0·25	5
1950	Essen	Cavity resonator	299 792·5 ± 1	1·5 (including systematic effects)
1950	Bol	Cavity resonator	299 789·3 ± 0·4	[2]
1951	Bergstrand	Optical, Kerr cell geodimeter	299 793·1 ± 0·2	5
1951	Aslakson	Radar	299 794·2 ± 1·9	13·5
1951	Froome	Radio interferometer	299 792·6 ± 0·7	2·5
1952	Rank, Ruth and Vander Sluis	Spectral lines	299 776 ± 7	[3]
1954	Froome	Radio interferometer	299 793·0 ± 0·3	0·7
1954	Rank, Shearer and Wiggins	Spectral lines	299 789·8 ± 3	[3]
1954	Florman [16]	Radio interferometer	299 795 ± 3·1	[3]
1954	Plyler [15]	Spectral lines	299 792 ± 6	[3]
		Most probable value	299 793·0 ± 0·5	

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[1] Work carried out in 1937–38.

[2] Details not given.

[3] Result obtained by a least squares analysis of the observations.

There is one further method, used by D. H. Rank and his collaborators [13], which should be mentioned because of its intrinsic interest and potential importance. It is based on the determination of the molecular constants of hydrogen cyanide by both optical and microwave spectroscopy. The results in one case are expressed in wavelength units, and in the other in terms of frequency; by combining the two the velocity, c_0, can be obtained.

These recent measurements by such very different methods have shown that there is no detectable change in the value of c_0 with frequency, and if realistic limits are placed on the earlier measurements there is also no evidence of any change with time.

It has often been asked how such a large error in the value of this important constant could remain undetected for so long, and it is important to find an answer to this question. The first point to remember is that prior to 1946 the values were obtained as the averages of large numbers of observations having a spread of about ± 50 km. In these circumstances it was not possible to investigate small systematic errors, although in two of the most important measurements, those by Michelson, Pease, and Pearson and by Anderson, the authors themselves called attention to such errors. In spite of these warnings, and perhaps misled by the elaborate scale of the experiments and the close agreement between the values obtained with very different apparatus, most reviewers of the subject gave their estimate of the most probable value with very small limits of error. But the evaluation of errors is very difficult even for the experimenters themselves, and must be far more difficult for anyone not having practical experience of the method. It is therefore not really surprising that the reviewers should reach erroneous conclusions about both the value and its accuracy. Moreover, the work of reviewers saves other scientists much tedious labour, and when their findings have been published the original papers are seldom referred to again. Any mistakes tend therefore to be perpetuated. Their value was in this instance so firmly held that a common reaction to the first cavity resonator result, in spite of its high accuracy compared with any previous determination, was that it was an interesting new experiment which would no doubt give the correct answer when the technique was perfected.

In the list of values given in the accompanying table the scatter of the experimental results is indicated, where possible, in addition to the limits given by the authors, in order to convey an idea of the precision of measurement.

REFERENCES

[1] Birge, R. T. *Rep. Progr. Phys.*, **8**, 90, 1941.
[2] Essen, L. and Gordon Smith, A. C. *Proc. roy. Soc. A.*, **194**, 348, 1948.
[3] Essen, L. *Ibid.*, **204**, 260, 1950.
[4] Bol, K. *Phys. Rev.*, **80**, 298, 1950.
[5] Froome, K. D. *Proc. roy. Soc. A.*, **213**, 123, 1952.
[6] Essen, L. and Froome, K. D. *Proc. phys. Soc. Lond. B.*, **64**, 862, 1951.
[7] Froome, K. D. *Proc. roy. Soc. A.*, **223**, 195, 1954.
[8] Bergstrand, E. *Ark. Fys.*, **2**, 119, 1950.
[9] Mackenzie, I. C. C. Appendix 6, Ordnance Survey Professional Papers, New Series, No. 19.
[10] Aslakson, C. I. *Trans. Amer. geophys. Un.*, **32**, 813, 1951.
[11] *Idem. Proc. Amer. Soc. civ. Engrs*, **77**, 1, 1951.
[12] Ross, J. E. R. Report for International Union of Geodesy and Geophysics. Tenth Annual Conf. 1954.
[13] Rank, D. H., Shearer, J. N., and Wiggins, T. A. *Phys. Rev.*, **94**, 575, 1954.
[14] Houstoun, R. A. *Proc. roy. Soc. Edinb. A.*, **63**, 95, 1950.
[15] Plyler, E. K. *J. opt. Soc. Amer.*, **44**, 507, 1954.
[16] Florman, E. F. *Ibid.*, **44**, 507, 1954.

The Perkin family of organic chemists

SIR ROBERT ROBINSON

This year is the centenary of the discovery of mauve, the first synthetic dye, by Sir William Perkin. The discovery had little significance in itself, but its possibilities—which Perkin had both the vision to see and the perseverance to translate into reality—were immense. He founded not only the manufacture of synthetic dyes but the whole organic chemical industry. Chemical talent was happily a family attribute and with two of his sons—William Henry junior and Arthur George—he played a major part in the development of organic chemistry in Britain. The achievements of this outstanding family are here saluted by a brilliant successor.

It is probable that the first laboratory designed for the teaching of chemistry was established by Lomonosov (1748) at St Petersburg, but the model for all later institutions was set up by Liebig at Giessen in 1824 and almost the whole later development of organic chemistry stemmed from this source. It seems, however, that one can have too much of a good thing, and when Liebig was invited to Munich in 1852 he accepted the call subject to the stipulation that he would be relieved from teaching duties.

A. W. von Hofmann, who entered the University of Giessen in 1836 as a law student, was soon attracted into Liebig's orbit and devoted himself to chemistry with outstandingly successful results; in 1843 he became Liebig's personal assistant. At about this time the authorities in England were seeking a professor for the Royal College of Chemistry, later absorbed into the Imperial College of Science. In view of the reputation of Liebig's school of agricultural chemistry it is not surprising that they sought to fill the post with a worthy representative of this group. The nomination of Hofmann for the professorship, in which the Prince Consort took an active interest, was made by Liebig. The period of nineteen years spent by Hofmann in England was of fundamental importance for three reasons.

First, the teaching of organic chemistry and the inspiration of organic chemical research in Britain derived very largely from Hofmann and his associates and pupils, although it is, of course, true that, as in a cyclotron, additional impulses of very great importance were received from time to time.

Second, the actual discoveries made—to quote but one example, in the chemistry of the amines—consolidated the theory of the infant science of the structural chemistry of carbon compounds.

Third, the foundations of the organic chemical industry were well and truly laid.

In all these developments, William Henry Perkin and his sons, William Henry and Arthur George, made essential contributions of different kinds and in varying degree. Sir William Perkin was not only a great organic chemist and discoverer, he was also a courageous man of character and determination. He must be reckoned among the great pioneers and he took frightening risks in trusting the clarity of his vision and the soundness of his judgment, often against the advice of his seniors, including Hofmann himself. William Henry Perkin, jun., can justly be estimated as a greater organic chemist than his father, but he sailed in relatively quiet waters and devoted himself almost exclusively to pure scientific work. Arthur George Perkin was also a star of the first magnitude, although brilliance is less apparent in this small constellation than it would be in comparison with other contemporaries.

The forebears of the Perkins were yeoman farmers in Yorkshire or Cumberland, and it is of interest that Thomas Perkin (born 1757) was locally reputed to have been interested in chemistry or alchemy: on the occasion of a pilgrimage to his grandfather's house near Ingleton, Sir William found a cellar fitted as a laboratory. Thomas moved to London, where he engaged in boat building and other forms of carpentry. His son, George Fowler Perkin, (born 1802), continued and extended this business, and William Henry Perkin was born at King David's Fort, Shadwell, on 12th March 1838. It was naturally hoped that this seventh son would carry on his father's trade, but, in his own words (New York, 1906)—'When I was between twelve and thirteen years of age, a young friend showed me some chemical experiments and the wonderful power of substances to crystallize in definite forms, and the latter, especially, struck me very much, with the result that I saw there was in chemistry something far beyond the other pursuits with which I had previously been occupied. The possibility also of making new discoveries impressed me very much. My choice was fixed, and I determined, if possible, to become a chemist and I immediately commenced to accumulate bottles of chemicals and to make experiments'.

His liberal-minded father was difficult to persuade that this decision was a wise one, but eventually withdrew all opposition and William left school at the age of fifteen, entered the Royal College of Chemistry in Oxford Street, London, and studied under Hofmann. He completed his first original investigation during his seventeenth year, and published his first paper in the Journal of the Chemical Society in 1856. His enthusiasm was such that he worked at home in the evenings and on holidays, in a laboratory which, though not lavishly equipped, was evidently quite adequate for many purposes. Here, at King David's Fort, he first investigated the reduction products of dinitrobenzene and dinitronaphthalene. The very interesting outcome of this work, done jointly with Church, was the discovery of a red substance 'nitrosonaphtyline' to which Hofmann himself adverted in 1856 and which Perkin and Church showed in 1857 could be produced more simply from a naphthylamine salt by the action of a nitrite. We now know that this substance is aminoazonaphthalene and it was the first definite azo-compound to be isolated. The dyeing properties of the substance were recognized and a patent was taken out in 1863. This is also of historic interest, in that it claims for the first time the production of a sulphonated azo-dye, made by applying the nitrite reaction to naphthylaminesulphonic acid. It remained for Peter Griess, also a student of Hofmann, to discover the aryldiazonium salts and to elucidate the mechanism of formation of the red substance of Perkin and Church.

It is stated in some texts that the discovery of 'mauve' was made by Perkin when working in Hofmann's laboratory, and the master's supervision is implied. This is not true: the work was independently contrived and executed in the home laboratory. However, it was the result of a remark of Hofmann that the synthesis of quinine ought to be possible and would be very desirable. At this time the relations of the molecular weights of simple organic compounds, such as alcohol and ether, had not long been established, chiefly by the admirable work of Williamson in 1852, and in regard to atomic weights this was the period of the classical paper of Cannizzaro. Very little was known about the molecular structure of any cyclic compound and, in fact, the whole splendid edifice of structural organic chemistry as we know it today, has been erected during the past century. In 1856, it was thought that a certain empirical composition was characteristic of each pure compound and hence that in order to synthesize a substance all that was necessary was to make a molecule having the desired composition. Thus, it was argued, quinine, $C_{20}H_{24}O_2N_2$, might be produced by the oxidation of two molecules of $C_{10}H_{13}N$ as shown in the equation:

$$2C_{10}H_{13}N + 3O = C_{20}H_{24}O_2N_2 + H_2O.$$

The nearest known substance was toluidine, C_7H_9N; to get $C_{10}H_{13}N$ from this, a hydrogen atom must be replaced by C_3H_5, that is by the known allyl group. Hence Perkin treated toluidine with allyl iodide, a reaction which afforded the desired allytoluidine, $C_{10}H_{13}N$. When this was oxidized with bichromate in acid solution, a brown precipitate was thrown down. Although no quinine was obtained, Perkin was interested in the reaction and tried the same process with simpler bases; with aniline sulphate and potassium bichromate he obtained a black precipitate, which he had the curiosity to examine. Boiling alcohol extracted a mauve colouring matter from it, and he soon found that this was able to dye silk and that the dyeings were relatively fast to light and washing. All this took place between Easter and June, 1856. He sent dyed patterns to Messrs. Pullar of Perth and as early as 12th June received the following:

'If your discovery does not make the goods too expensive, it is decidedly one of the most valuable that has come out for a very long time. This colour is one which has been very much wanted in all classes of goods and could not be obtained fast in silks, and only at great expense in cotton yarns. I enclose you a pattern of the best lilac we have in cotton—it is dyed by only one house in the United Kingdom, and does not stand the tests that yours does, and fades by exposure to air'.

Thus encouraged, Perkin never looked back. With the most admirable perseverance, assisted by his elder brother, Thomas D. Perkin, he overcame one formidable obstacle after another, and founded not only the manufacture of synthetic dyes but also the whole organic chemical industry. He quickly decided to attempt the commercial exploitation of his discovery and was greatly helped by his father who, in Perkin's words, 'very nobly risked most of the capital he had accumulated in a life of great industry in order to build and start works for the production'.

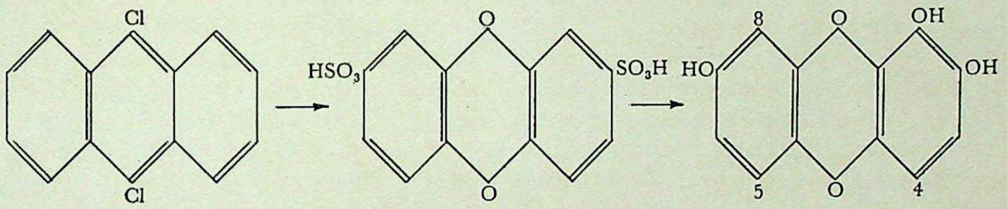
But Hofmann, whom he informed of his intentions in October, was discouraging, not to say annoyed, and indicated that this false step might ruin a promising career. Still Perkin persisted, not at all dismayed by his lack of experience of chemical engineering. The reason for this, mentioned by Sir William in all seriousness, was that the operations to be carried out were of such a novel character that there was little scope for imitation of existing practice. It is this active, forceful pioneering which gives Sir William Perkin his real claim to fame. The discovery of mauve was an example of sharp observation, but it had very little significance in itself. The really important thing was that the young Perkin had a vision of the possible future. It almost seems now that he was inspired with a sense of mission, and he never faltered when this took him into the unfamiliar realms of chemical technology and commerce. The generous impulse of his young blood, his quick enthusiasm, carried him away from the pursuit of pure chemistry, though only to a certain extent. He was always busy with some researches of the kind miscalled academic, and later in life returned to the fold from which he had strayed. Nevertheless, it cannot be too strongly emphasized that William Perkin was the real pioneer of the organic chemical industry not because he discovered mauve but because he set to work to manufacture and to sell it.

The difficulties in his way can hardly be overestimated. In the first place benzene, which had been separated from coal tar by Hofmann's pupil, Mansfield, only a short time previously, was made on only a very limited scale. A crude product was eventually secured from a Glasgow firm; it cost 5s. per gallon and had to be carefully fractionated. Again, the preparation of nitrobenzene had been accomplished only by the use of fuming nitric acid on a small laboratory scale. It was Perkin who introduced the use of a mixture of nitric acid, (*d* 1·3 or thereabouts) or sodium nitrate, and sulphuric acid, and he soon adopted cast iron vessels instead of the glass flasks hitherto thought necessary for such operations. None of these major technical advances was achieved without teething troubles, such as explosions, but Perkin's courage carried him through and his methods were soon adopted by others. For example, the firm of Simpson, Maule and Nicholson manufactured nitrobenzene (and later aniline), and Perkin and Sons obtained supplies from them when the demand for mauve became so great that the works at Greenford Green, near Harrow, could not cope with it.

In 1854 Béchamp had found that nitrobenzene could conveniently be reduced to aniline by means of iron filings and dilute acetic acid. With similar perseverance Perkin made this process a technical success and it should not be necessary to emphasize that the manufacture of aniline and its homologues greatly strengthens his claim to be regarded as the founder of the industry and not merely the fortunate discoverer of a colouring matter.

It is characteristic of the synthetic colour industry that it is subject to continuous change through the introduction of new products: this was true at the start and remains true today. Perkin's discovery of mauve stimulated others to experiments on the oxidation of aromatic amines, and one of the first fruits was the discovery of Magenta by Verguin in 1859. This dyestuff was manufactured by Perkin and Sons using the mercuric nitrate process (Knosp, 1859; E. P., T. D., Perkin). A range of other dyestuffs of the basic type manufactured included Dahlia, made by the action of ethyl iodide on Mauve, Safranine (Grenville Williams, 1859), and Britannia Violets, made by heating Magenta in methanolic solution with brominated turpentine under pressure. These dyes had a range of shades, and a blue variety was partly converted into the successful Perkin's Green by heating with acetyl chloride. In this connection the manufacture of phosphorus trichloride, and of acetyl chloride, was first carried out.

A development of importance almost equal to that of the triphenylmethane and azine dyes was the production of artificial alizarine. This colouring matter of madder had been regarded as related to naphthalene, and only in 1868 was it recognized by Graebe and Liebermann to be a derivative of anthracene. A year later they disclosed a synthesis—the first of a complex natural colouring matter—based upon fusing a dibromoanthraquinone with potassium hydroxide. As Perkin's earliest work under Hofmann's guidance had been concerned with the isolation of anthracene from coal-tar and with the preparation of anthraquinone and chloro-anthracene, he was in a good position to attack the problem of alizarine synthesis on an industrial scale. The synthesis of phenol from benzenesulphonic acid by alkali fusion was discovered by Kekulé and Wurtz in 1867 and Perkin decided to try and make anthraquinonedisulphonic acid in the hope of applying the same reaction to the formation of alizarine. The patent describing the successful development of this idea was one day later in date than a similar one taken out in Germany by Caro, Graebe, and Liebermann. An agreement was negotiated by which the English rights were allotted to Perkin and Sons. Not very much later, in 1869, Perkin superseded his earlier method by one dependent on the sulphonation of 9:10-dichloroanthracene with formation of anthraquinonedisulphonic acid. The 'alizarine' made by the first method contained anthrapurpurin and flavopurpurin, whereas that obtained by the new process was more correctly described as anthrapurpurin (1:2:7-trihydroxyanthraquinone) containing some alizarine and some flavopurpurin.



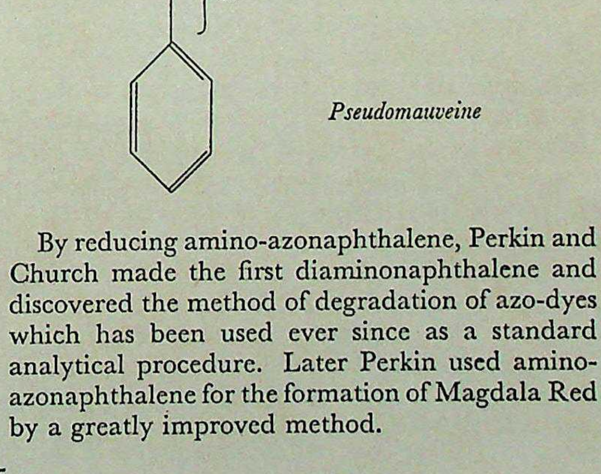
Only much later was it realized that the alkali fusion involved oxidation, that anthraquinonemonosulphonic acid is the intermediate for alizarine, and that the yield can be increased by the addition of an oxidizing agent (nitrate, chlorate) to the melt.

In 1869 Perkin and Sons made 1 ton of alizarine paste, and in 1873, 435 tons. But in 1874, the Greenford Green works was sold by Perkin to Messrs Brooke, Simpson, and Spiller, who later transferred it to Messrs Burt, Bolton, and Haywood. This firm moved the alizarine manufacture to Silvertown, where the enterprise became The British Alizarine Co. Perkin was thus the prime mover in founding two quite distinct branches of the artificial colour industry, and it should be added that he also introduced the system of technical service to dyers and other customers which later became such a powerful weapon in the hands of the German manufacturers.

After his retirement from business at the age of 36 Perkin devoted himself to pure research. A few of his contributions to pure science were the following.

In 1858 he effected, with Duppa, the first synthesis of glycine, by heating a solution of bromoacetic acid in aqueous ammonia. The same authors cleared up many aspects of the relation between maleic and fumaric acids and the isomeric tartaric acids. They could not, of course, at that stage of the development of the subject, reach a full understanding of the problems involved. The synthesis of DL-tartaric acid from dibromosuccinic acid was due to the same workers.

Mauve was separated by Perkin into three constituents and he identified the bases in his starting material which gave rise to each. Though a general idea of their structure was reached, the constitution of one of these substances was first settled by the synthesis of Perkin's pseudomauveine by O. Fisher and Hepp in 1888. This was the component derived from aniline only and the synthesis proved that it had the annexed structure.



Pseudomauveine

By reducing amino-azonaphthalene, Perkin and Church made the first diaminonaphthalene and discovered the method of degradation of azo-dyes which has been used ever since as a standard analytical procedure. Later Perkin used amino-azonaphthalene for the formation of Magdala Red by a greatly improved method.

A quite different field was opened up by Perkin's synthesis of coumarin from the sodium salt of salicylaldehyde and acetic anhydride (1868). This was followed up by the general Perkin reaction, the synthesis of cinnamic acid and derivatives, in 1877. This sequence recalls the similar example of Graebe's discovery of Alizarine Blue, later developed by Skraup as a general method of synthesis of quinoline derivatives.

From 1881, Perkin devoted most of his attention to a study of the effect of a magnetic field on the optical rotatory power of organic substances. He related the magnitude of the effect to structure in a masterly manner and showed that his results ran parallel to those obtained in a similar study of refractive and dispersive powers. His last paper (1907) was on the magnetic rotation and refractive power of hexatriene and the relationship of this substance to benzene.

WILLIAM HENRY PERKIN, JUN.

In 1859 Perkin married his cousin, Jemima Harriet Lissett, who was of Huguenot descent. Their first-born was William Henry (1860), followed (1861) by Arthur George. Mrs. Perkin died shortly afterwards, a victim of tuberculosis. Six years later Perkin married Alexandra Caroline Mollwo, by whom he had a son, Frederick Mollwo, and four daughters.

The financial success of the works at Greenford Green and the early stage at which Perkin left his great work to be carried on by others, together with his preoccupation with scientific work, doubtless smoothed the path for his eldest son and indicated a career in pure science. But the chief contributory factor to the fortunate outcome was the chemical talent, amounting to genius, which William Henry Perkin, jun., showed that he possessed from the time when he first touched a test-tube. He studied for a time in Frankland's laboratory at the Royal College of Chemistry (1877), which had been transferred from Oxford Street to South Kensington. Here he carried out some researches under W. R. E. Hodgkinson. One of these, 'On the action of sodium on phenylic acetate', published in the Journal of the Chemical Society, will be recognized as truly Perkinian by the cognoscenti.

In the house at Sudbury in which the Perkins then resided there was a laboratory in a building in the garden, and both the sons worked there in the vacations. So far as the writer is aware the only recorded collaboration between the brothers was a study of the pyrolysis of silver salt (sodium anthraquinone-β-sulphonate), and of other derivatives of anthraquinone; this may have been merely the result of propinquity, though the work was published later, in 1885 and 1888. It is strange that the young chemists overlooked the fact that the red product, which was in fact di-anthraquinonyl sulphide, contained sulphur!

In 1880, William went to Würzburg and studied under Wislicenus, though not without some serious opposition from his father, who feared that in Germany his son would be too much exposed to the influence of free-thinkers. Perkin has given an eloquent tribute to Wislicenus in a Memorial Lecture delivered to the Chemical Society. However, after a brief interlude in his father's laboratory, he joined the brilliant group that clustered round Adolf von Baeyer at Munich. He became an ardent disciple, and later a close friend, of that great man, to whom for a long period he made an annual visit. Baeyer set him to work to study the reactions of benzoylacetic acid and its esters. At that time the elegant method of Claisen was not known and the acid had to be made by reacting phenylpropiolic acid with sulphuric acid and later with water:

$$\mathrm{Ph.C \equiv C.CO_2H + H_2O \rightarrow Ph.CO.CH_2.CO_2H}$$

The acetylenic acid was made from cinnamic acid dibromide by the action of alcoholic potash, and the yield was rather poor in the last stage. Baeyer, in his round of the laboratory, was astonished by the amount of benzoylacetic ester that his new pupil had accumulated and began to read him a lecture on undue prodigality in the use of material. But Perkin had discovered a better method, and on this being explained Baeyer's reported comment (from W.H.P. to the writer) was, 'I see you are not so great a fool as I took you to be'.

Perkin became a privatdozent at Munich and took full advantage of his exceptional opportunities not only for communion with kindred spirits, such as Königs, Bamberger, Curtius, von Pechmann, Friedländer, O. Fischer, and many others, but also for participation in the typical life of the University and the enjoyment and practice of music. It should be noted that all the Perkins were musicians and there was a family orchestra of almost professional calibre.

It was here that he started one of his most original and far-reaching researches, that on the synthesis of substances whose molecules contained carbon rings, even those of three or four atoms.

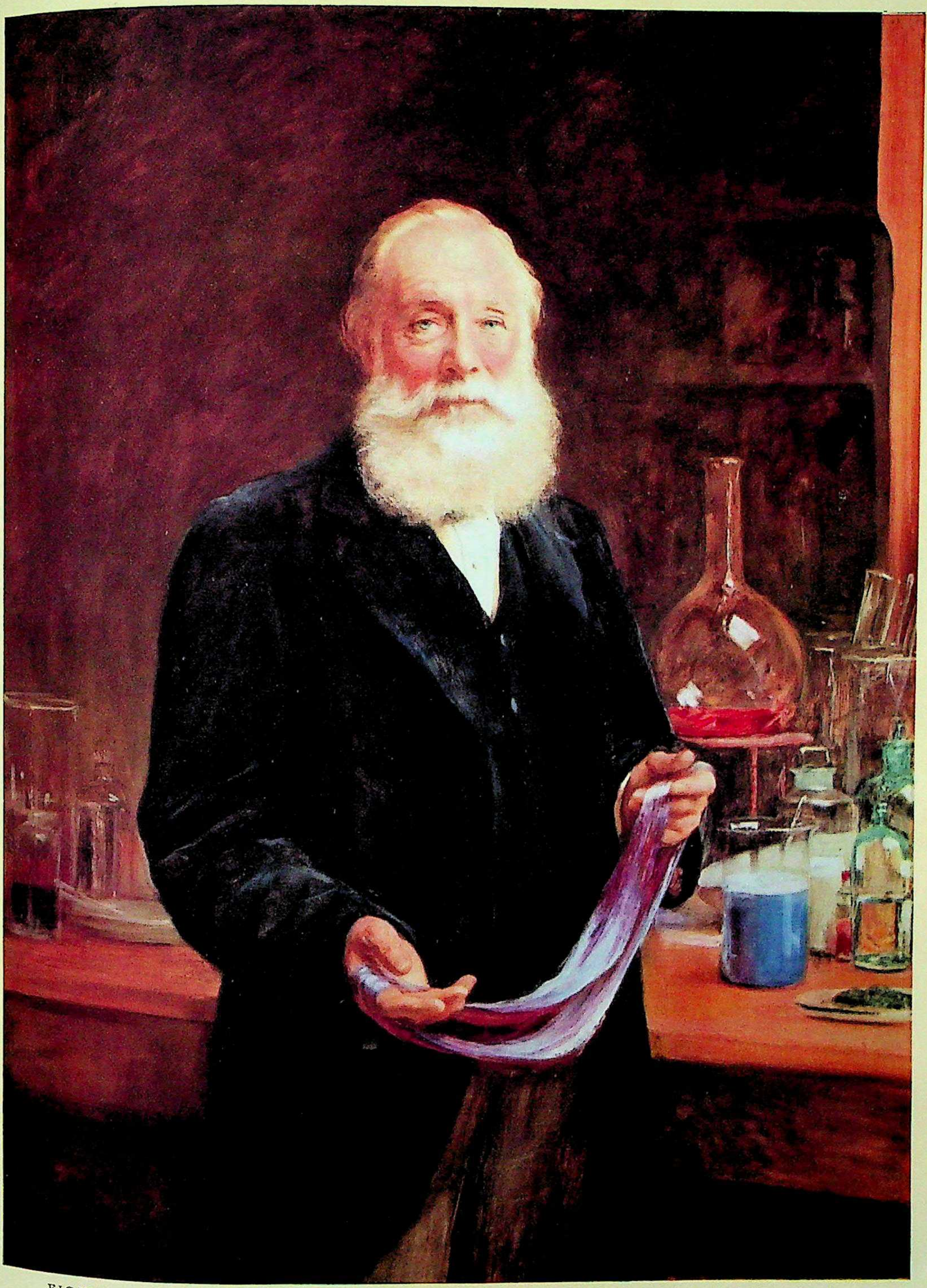


FIGURE 1 – *Sir William Perkin, from a painting by A. S. Cope in the National Portrait Gallery, London.*

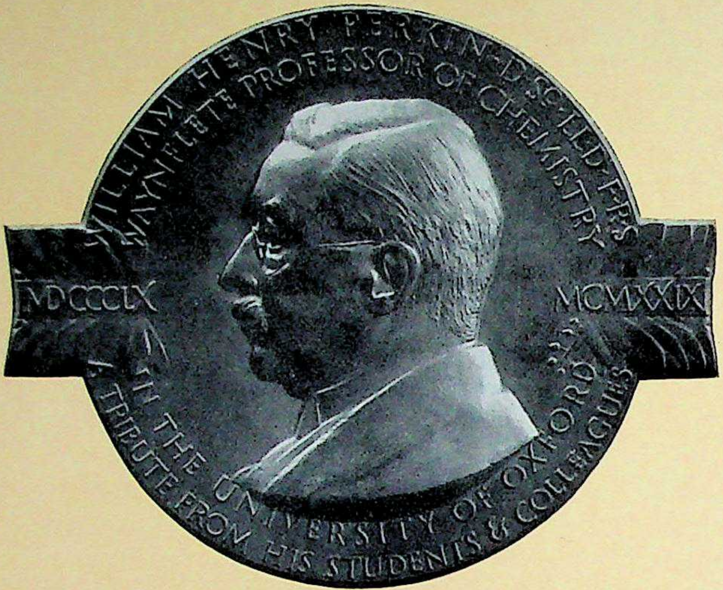

WILLIAM HENRY PERKIN · D.SC. · LL.D. · F.R.S.
WAYNFLETE PROFESSOR OF CHEMISTRY
MDCCCLX
MCMXXIX
IN THE UNIVERSITY OF OXFORD
A TRIBUTE FROM HIS STUDENTS & COLLEAGUES

FIGURE 2 – *W. H. Perkin, jun., from a memorial plaque in the Dyson Perrins Laboratory, Oxford.*

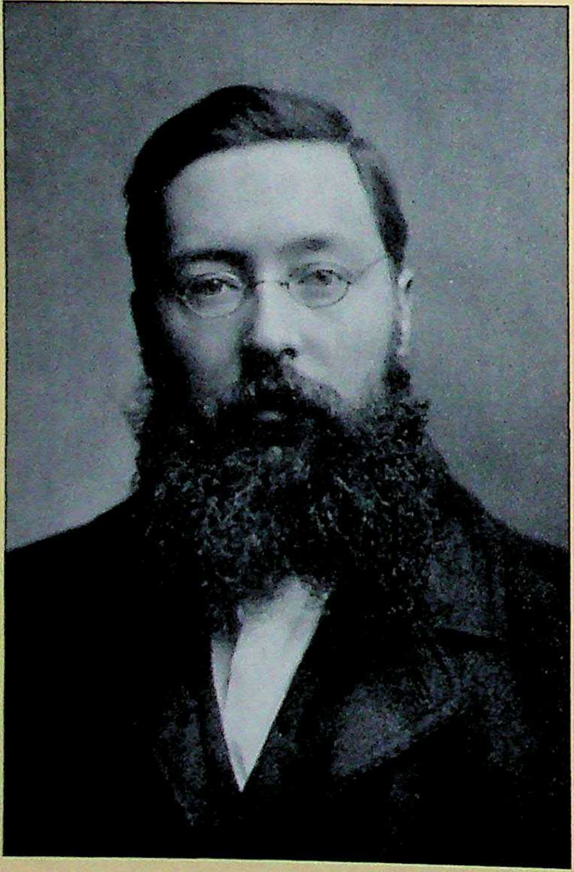


FIGURE 3 – *W. H. Perkin, jun.*

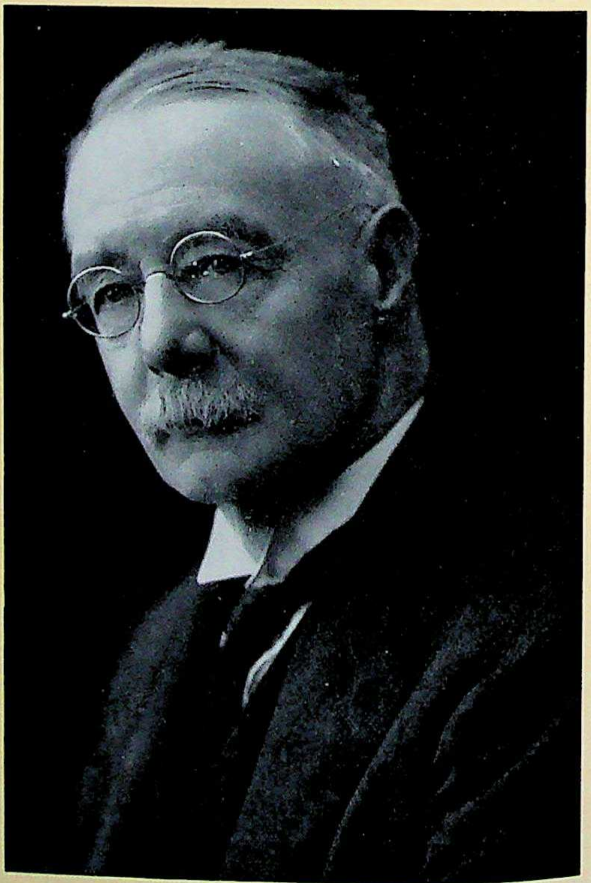


FIGURE 4 – *A. G. Perkin.*

Victor Meyer frequently visited Munich and on one occasion had a long discussion with Perkin in regard to his plans for this investigation. Meyer deprecated the idea, because he thought that only five-membered and six-membered rings could exist; at least there was then no evidence that other types occurred in natural products or had been obtained in synthetical work. Emil Fischer and Baeyer himself joined their voices to that of Meyer. Their argument was certainly valid at the time, but Perkin quickly proved that it was nevertheless fallacious, because he found several methods for the production of the smaller carbon rings, as well as for those of the more usual types. This discussion of plans for a research strikes no familiar chord nowadays. The standards of courtesy have sadly deteriorated, and in place of consultation we find a Provisional Patent in the form of a Preliminary Note: even this is often infringed.

At a little later stage he became involved in a controversy with Fittig, who threw doubt on the correctness of Perkin's view of the nature of his *cyclo*-propanecarboxylic acid (trimethylenecarboxylic acid); Fittig thought it was probably vinylacetic acid. However, the synthesis of the latter by J. Wislicenus settled the matter in Perkin's favour. The ramifications of this work cannot be followed in such a brief account as this; a much later development was the work on camphor and the syntheses of limonene, sylvestrene, and the terpineols, the latter being *Analogie-Arbeiten*, but of the most elegant kind.

As a result of a meeting with H. B. Dixon at Montreal, during the Canadian meeting of the British Association for the Advancement of Science in 1884, he returned from Munich to Manchester for a short period and there started his important studies on brazilin and haematoxylin. The work did not progress far at that time, but was taken up again on the return to Manchester in 1892.

After failing to secure the Chair at Aberdeen (F. R. Japp was appointed and thoroughly deserved and justified his success), he became Professor of Chemistry at the Heriot Watt College in Edinburgh and five years later accepted the invitation to fill the Chair of Organic Chemistry at Owens College rendered vacant by the death of Carl Schorlemmer. Here he developed a remarkable school of research and was influential in promoting extensions of the facilities, making plans for new buildings which were, however, carried out only in part during his tenure of the Chair.

In 1912 he was elected Waynflete Professor of Chemistry, Oxford University, and Fellow of Magdalen College. There he continued with unabated vigour his brilliant researches, attracted eager pupils from many parts of the world, and left his mark on the University and its chemical school; it suffices to mention the Dyson Perrins Laboratory and the Part II of the Honour School.

If a more complete account of Perkin's work is desired, the reader may be referred to the considerable Obituary Notice published by the Chemical Society (1932), where it will be found summarized in over 100 pages. But in addition to his varied synthetical work, two aspects of his research activity must be specially mentioned here.

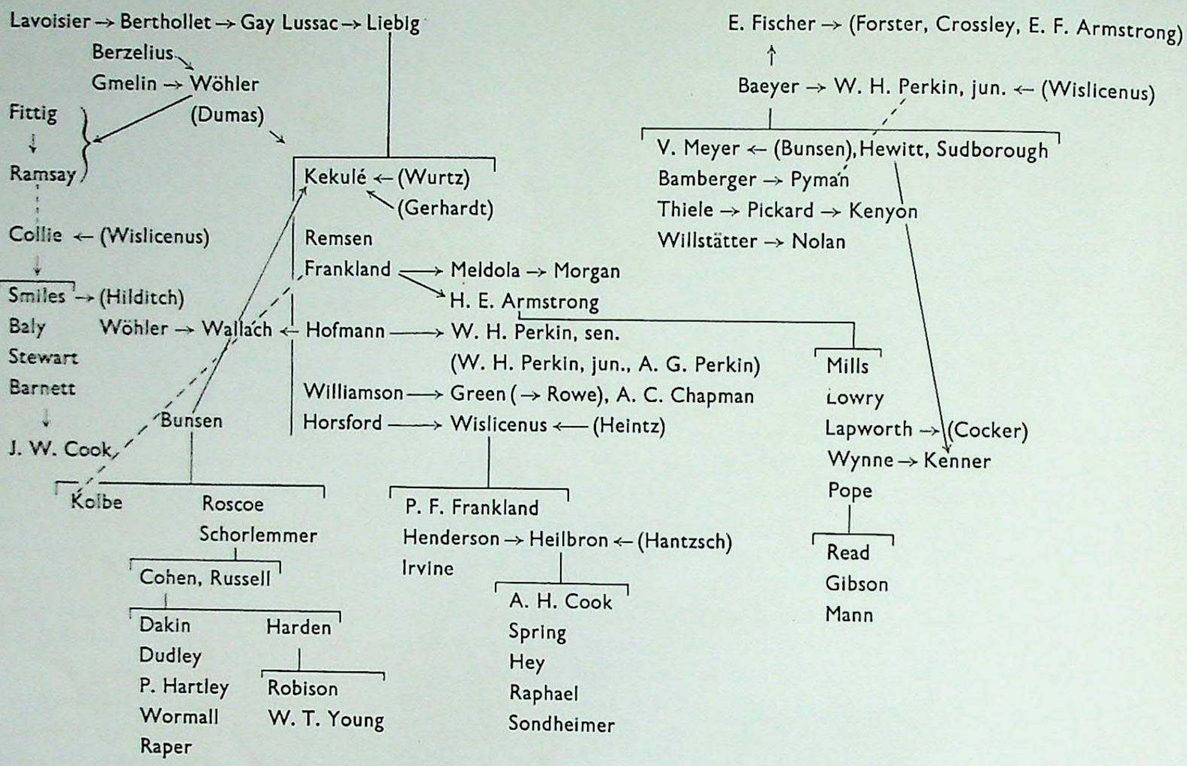
Goldschmiedt, over a period of years from 1883, was the first to attack the constitution of a natural product, in this case papaverine, by oxidation of the substance with potassium permanganate, so as to form a variety of products the nature of which could be determined more easily at least than that of the progenitor. These simple molecules were thus the pieces which could be fitted together, often overlapping, so as to reconstitute the original, as in a jig-saw puzzle.

At Edinburgh and Manchester, and with some projection to Oxford, Perkin applied the idea with conspicuous success to the complex alkaloid berberine and to brazilin and haematoxylin, in the latter cases using methyl ethers. In his exhaustive study of cryptopine, and again in his work on strychnine and brucine, the method was somewhat different and consisted in a study of all the transformations which he could effect of the complex molecules. Perkin modelled himself on Baeyer and developed to an extraordinary degree the qualities which he most admired in the master. At all times he worked in the laboratory most assiduously with his own hands and had a wonderful, uncanny instinct for the selection of the best methods for the separation of the constituents of tars and suchlike unpromising material.

He had little interest in theoretical chemistry. For him chemistry was an art or craft designed to embellish the edifice of molecular structural knowledge. This was erected largely during his lifetime, and he made great additions to it himself. He was, however, quick to adopt new techniques when he was sure of their value; for example, he became very skilled in high-vacuum distillation.

As a lecturer, and teacher generally, he was extremely successful, and his fame in this respect is recognized not merely by the organic chemists who were fortunate enough to collaborate with him in original work, but also by the larger number

PART I


Lavoisier → Berthollet → Gay Lussac → Liebig
Berzelius
Gmelin → Wöhler
(Dumas)
Fittig
Ramsay
Collie ← (Wislicenus)
Smiles → (Hilditch)
Baly
Stewart
Barnett
J. W. Cook
Wöhler → Wallach ← Hofmann
Bunsen
Kolbe
Roscoe
Schorlemmer
Cohen, Russell
Dakin
Dudley
P. Hartley
Wormall
Raper
Harden
Robison
W. T. Young
Kekulé ← (Wurtz)
(Gerhardt)
Remsen
Frankland → Meldola → Morgan
H. E. Armstrong
Hofmann → W. H. Perkin, sen.
(W. H. Perkin, jun., A. G. Perkin)
Williamson → Green (→ Rowe), A. C. Chapman
Horsford → Wislicenus ← (Heintz)
P. F. Frankland
Henderson → Heilbron ← (Hantzsch)
Irvine
A. H. Cook
Spring
Hey
Raphael
Sondheimer
E. Fischer → (Forster, Crossley, E. F. Armstrong)
Baeyer → W. H. Perkin, jun. ← (Wislicenus)
V. Meyer ← (Bunsen), Hewitt, Sudborough
Bamberger → Pyman
Thiele → Pickard → Kenyon
Willstätter → Nolan
Mills
Lowry
Lapworth → (Cocker)
Wynne → Kenner
Pope
Read
Gibson
Mann

PART II

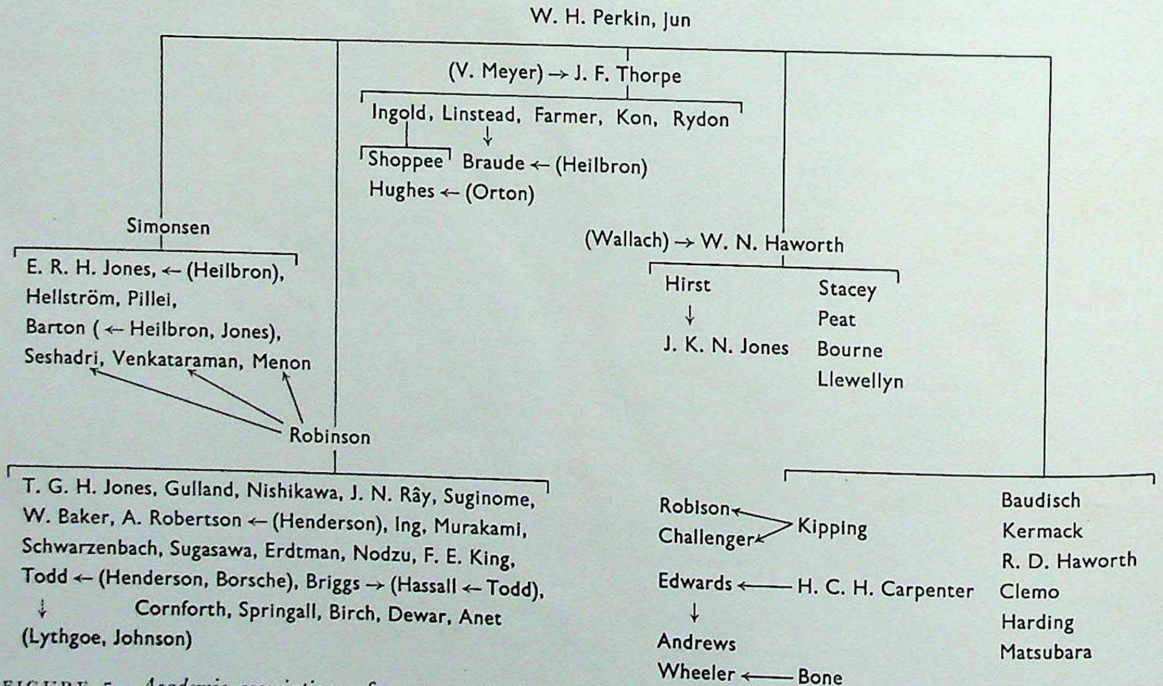

W. H. Perkin, jun
(V. Meyer) → J. F. Thorpe
Ingold, Linstead, Farmer, Kon, Rydon
Shoppee
Braude ← (Heilbron)
Hughes ← (Orton)
Simonsen
E. R. H. Jones, ← (Heilbron),
Hellström, Pillei,
Barton (← Heilbron, Jones),
Seshadri, Venkataraman, Menon
Robinson
T. G. H. Jones, Gulland, Nishikawa, J. N. Rây, Suginome,
W. Baker, A. Robertson ← (Henderson), Ing, Murakami,
Schwarzenbach, Sugasawa, Erdtman, Nodzu, F. E. King,
Todd ← (Henderson, Borsche), Briggs → (Hassall ← Todd),
Cornforth, Springall, Birch, Dewar, Anet
(Lythgoe, Johnson)
(Wallach) → W. N. Haworth
Hirst
J. K. N. Jones
Stacey
Peat
Bourne
Llewellyn
Robison
Challenger
Kipping
Edwards ← H. C. H. Carpenter
Andrews
Wheeler ← Bone
Baudisch
Kermack
R. D. Haworth
Clemo
Harding
Matsubara

FIGURE 5 - *Academic associations of some organic chemists, primarily designed to illustrate the far-reaching influence of W. H. Perkin, jun.*

of undergraduates who attended his lectures and retained the most vivid memories of his highly characteristic lucidity of exposition.

A favourite expression was 'Let us put it down in the form of a little table': accordingly the writer has thought it appropriate to show in a similar fashion the profound influence, or at least a part of it, of W. H. Perkin, jun., on organic chemistry in Britain.

The annexed table (figure 5) illustrates, although in a manner certainly incomplete and probably in some respects fallacious, the academic relations of some British chemists. The chief object has been to show the influence of W. H. Perkin, jun., but to do this in a fully satisfactory manner would fill several pages: hence directors of research, and others engaged in technical, administrative, or quasi-confidential work, have not been mentioned. Those who have occupied chairs in universities or have been admitted into the Fellowship of the Royal Society are included, but even so there will be omissions due to the limited knowledge of the author.

ARTHUR GEORGE PERKIN

Arthur George Perkin was a weak infant and was not expected to live. At the age of six he went to a boarding school at Margate and when ten years of age he joined William at the City of London School. Hence his home life was confined to vacations, when the chief occupation of both boys was to carry out chemical experiments in the garden laboratory, where there was a bench for each under opposite windows. At the age of seventeen he entered the Royal College of Chemistry and studied under Frankland and Guthrie. He did some original work and published a paper on 'The Action of Nitric Acid on Di-*p*-tolylguanidine' in 1880.

When William went to Würzburg, Arthur spent a year at Anderson's College, Glasgow, and then won a scholarship, newly instituted by the Worshipful Company of Clothworkers, tenable in the Dyeing Department of the Yorkshire College, later the University of Leeds.

Here he worked with J. J. Hummel, for whom he always professed the greatest admiration, and this contact orientated his chemical interest in the direction of the chemistry of natural dyestuffs. This subject he made his own, and his contributions in the field gave him international fame and permanent recognition as a pioneer. One piece of joint work with Hummel concerned the action of strong acids, for example, sulphuric acid, on brazilein and haematein. The so-called isobrazilein and isohaematein salts thus produced were the first pyrylium derivatives to be isolated and analysed, though the true nature of the substances could not be understood in those early days. On the expiry of his scholarship, Perkin accepted an appointment as chemist in the firm of Hardman and Holden of Manchester. He was doubtless influenced in the decision to take up this work by the nature of their business, which was concerned with the manufacture of artificial alizarine. In 1888 he became manager of the works.

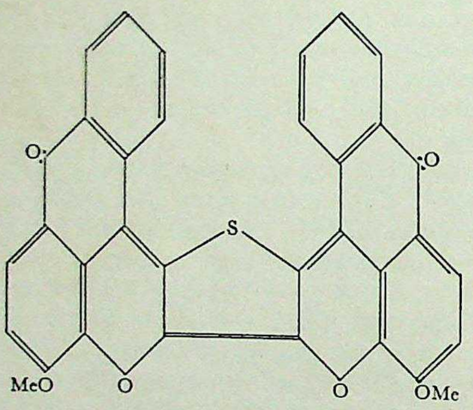
In 1892 he went back to the Yorkshire College as lecturer with research duties. The opportunity was seized to the full, and for a long period of years he worked assiduously day, and sometimes night, often assisted by his wife (*née* Bedford), studying the constituents of dyewoods and other sources of natural colouring matters. He was especially interested in the naturally occurring dyestuffs, and this directed his steps towards the anthoxanthins and above all to the flavonoid types.

In 1916, Perkin succeeded A. G. Green as Professor of Colour Chemistry and Dyeing in the University of Leeds. His teaching and administrative duties gradually became more onerous, and matters were not improved by the extreme conscientiousness which was characteristic of him. The writer can give an instance of this from his own experience: acting occasionally as his External Examiner it was possible only to admire, with what patience could be summoned, Perkin's practice of reading aloud every word of every script.

According to F. M. Rowe, his successor in the chair, this increase of routine led him in later years to devote his attention to less arduous studies. Nevertheless he worked constantly and personally to the end of his life and the investigations of the later years do not show any faltering of one of the most skilful pair of hands which has served our science.

He retired in 1926 and died in 1937. Although he had many collaborators, both British and from abroad, about 60 of his 270 memoirs were published in his own name alone. He was indeed essentially an individual worker, happiest with a single objective at any one time and not possessing in a comparable measure his brother's flair for the organization of research on a wide front. Throughout his life Perkin worked on derivatives of anthraquinone, particularly the hydroxylated substances of natural origin. He paid special attention to the partly methylated di- and trihydric phenols of the group and devised methods for determining their structure and for their synthesis.

From 1922 to 1933 he examined the reduction products of the hydroxy-anthraquinones, determined the structure of the products, and showed how they could be condensed into bis-anthracene derivatives including naphthadianthrones and helianthrones. His very last work, with N. H. Haddock, arose from this topic. In attempting the methylation of 3:4-dihydroxyanthranol, a green vat dye was obtained and the formation of the substance was found to be due to an impurity in the trichlorobenzene used as the reaction medium. This was identified as tetrachlorothiophene, and the probable constitution of the colouring matter is as shown below.



The kernel of Perkin's scientific work was a long series of researches on flavones and flavonols of natural origin.

The natural yellow dye weld (from Dyers' Weed, *Reseda luteola*) was known to the Gauls in the time of Julius Caesar. Its colouring principle was first studied by Chevreul and later by other workers, but nothing was known in regard to the structure of its molecules. Perkin improved the method of isolation of this luteolin and showed that it is a tetrahydroxyflavone based on phloroglucinol and catechol. Many years after luteolin had been generally abandoned, the silk facings of military uniforms were dyed by means of its bright yellow aluminium lake. Similarly mauve, otherwise long superseded, was used to colour the lilac penny postage stamp of Queen Victoria's reign.

Perkin was not the first to recognize the nature of the flavonoid colouring matters. Earlier work by Herzig (fisetin) and Kostanecki, and Piccard (chrysin) laid the foundations, but because of his great extensions of the group he must be ranked with the above-named pioneers. It suffices to mention apigenin (first isolated by von Gerichten), acacetin, morin, myricetin, quercetagetin, gossypetin, rhamnetin, *iso*rhamnetin, among many others. Perkin also encountered many substances allied to the flavones, such as butin and butein (from *Butea frondosa*) and in addition studied xanthones, such as gentisin. He garnered the information which later led to the recognition of the existence of the isoflavones.

A brand plucked from the burning was carajurin, once used as a cosmetic pigment by the natives of the Upper Orinoco. Perkin obtained a specimen from a curio dealer in London, but the secret of its preparation appears now to be lost. The material afforded two crystalline substances, of which the more abundant was the deep red carajurin. The writer was privileged to take part in the determination of the structure of carajurin and it has recently been synthesized by Seshadri. Incidentally it should be mentioned that Indian and Japanese chemists have greatly enlarged our conceptions of the importance of the flavonoids, and the influence of A. G. Perkin on the direction taken by their work is easily discerned.

Perkin also made significant contributions to our knowledge of the catechins and discovered the curious substance cyanomaclurin, which has the composition and structure of a reduced morin, intermediate in state of oxidation between a catechin and a flavonol. Perkin's strong suit was the accumulation of 'know-how' for handling these and other natural products.

FREDERICK MOLLWO PERKIN

The third son of Sir William Perkin, Frederick Mollwo, collaborated with Arthur in some work on the production of purpurogallin. He wrote a textbook on qualitative analysis and one recalls with gratitude that the composition of certain named reagents, such as Mandelin's, was given therein. This is a matter which is often obscure.

As in the case of the important chemical technologists who owed so much to the early inspiration given by W. H. Perkin, jun., it is impossible to assess the value of confidential work by reference to detail. It is clear, nevertheless, that the overall effect has been important. This consideration applies to Perkin's third son, whose success as a technical consultant showed that he inherited one aspect of Sir William's genius, and that, as we have tried to show, by no means the least important aspect.

सन्दर्भ ग्रन्थ
REFERENCE BOOK

Book reviews

DICTIONARY OF SCIENCE

Kosmos Lexikon der Naturwissenschaften, Volume 2, L–Z. *Pp.* 904. *Kosmos Gesellschaft der Naturfreunde; Frankh'sche Verlagshandlung, Stuttgart.* 1955. *Cloth, DM.* 35.50; *Leather, DM.* 42 *net.*

The first volume of this dictionary was reviewed in *Endeavour* in April 1954: the second volume completes the work, which can now be viewed as a whole. More than 25,000 terms, covering many branches of science, have been compiled and explained by specialists; among the biological sciences, which are specially stressed, zoology seems to have been particularly favoured, as the list of contributors shows nine zoologists as compared to one from each of the other branches of science dealt with.

As a reference book for non-scientists interested in the impact of science on the modern world this book will serve a very useful purpose, and the literature cited is in many instances up to date and will stimulate further reading. It seems, however, that the fact that each reference was dealt with by a specialist has led to a certain neglect of those fields of research where two or more branches of science overlap, such as biochemistry and biophysics, though these also might be of interest to a general reader.

The table on the development of mankind (columns 1863–65) might appear rather bewildering to the layman, and the survey of the history of the sciences contained in ten columns cannot be of real value, even to a non-scientist.

Seen as a whole, the dictionary is an admirable achievement, and with its clear drawings and delightful coloured plates will certainly become one of the most popular of the Kosmos publications.

G. SCHLESINGER

LOGOTECHNICS

Composition of Scientific Words, *by Roland Wilbur Brown. Pp.* 882. *Published by the author, from the U.S. National Museum, Washington.* 1954. $8 *net.*

Because of the need for a concise way of denoting new and complex ideas the sciences have been prolific begetters of new words, many of which have come into general usage. Most are derived from Latin and Greek roots, but the decreasing attention paid to the classical languages in the early education of scientists has, among other causes, led to many unsatisfactory developments in nomenclature. The author of the present book—a greatly enlarged version of his 'Materials for Word-Study' (1927)—has made a lifelong hobby of the practical application of Latin and Greek in the formation of literary and scientific terms. All those who are interested in the writing of good English must be profoundly grateful to him for putting the results of his studies permanently on record. The book's purpose is twofold. On the one hand to mitigate some of the ills of word composition: on the other to discourage the making of unnecessary words and the prolification of jargon.

Although the bulk of the book consists of a cross-reference lexicon of words and roots, there are also excellent introductory sections which include discussion of the nature of Latin and Greek and rules for deriving scientific terms from them. While the weight of emphasis is naturally on the classical languages, the host of others—from Sanskrit and Polynesian to Anglo-Saxon and aboriginal American—which have contributed to the richness of English receive due mention.

But one word of warning must be offered to the intending user. Unless his firmness of purpose far exceeds that of the present reviewer he will find much time slipping pleasantly away in perusing entries far removed from those he originally intended to seek. Time so lost will not by any means be wasted, however, for any amount of browsing in this book will be profitable.

TREVOR I. WILLIAMS

A SYSTEM OF NATURE

The Unified System Concept of Nature, *by S. T. Bornemisza. Pp. viii* + 137. *Vantage Press Inc., New York.* 1955. $3 *net.*

This is an unusual kind of book. The author seeks to arrive at a general view about living and non-living systems in nature, their ordering into hierarchies of different complexity, and their interrelations. He begins by contrasting recurrent or cyclic changes with discontinuous structural changes, and distinguishes what he calls the internal and the external relations of systems, pointing out how the external relations of one set may be the internal relations of a set of different order. In this general connection the principle of entropy compensation becomes very important. Biological systems are then considered, and a doctrine of what is called the 'organic image' is propounded according to which 'living organic matter harbours the reproduction of its environment'. This organic image contains elements not only of the past, as in memory, but of the future, in that it determines heredity.

The latter part of the book tackles the question of psychophysical parallelism. The author seems to subscribe to the form of doctrine which finds some element of the living in everything.

Generally speaking, the book is based on sound scientific principles. The philosophical discussion at times strikes the reader as illuminating and even eloquent, and at others nearly as an embroidery of the obvious. The talk about organic image may seem to some a little far-fetched, but it has at least many elements of truth. Some of the attempts at analysis of the relation between the physical and psychological are necessarily very speculative, but on reflection one may feel that they are not more surprising than much that is the common currency of psychoanalysis.

C. HINSHELWOOD

THE RENAISSANCE AND EARLY SCIENCE

The Appreciation of Ancient and Medieval Science during the Renaissance (1450–1600), *by George Sarton. Pp. xvii* + 233. *University of Pennsylvania Press, Philadelphia; Geoffrey Cumberlege, London.* 1955. $5 *net.*

If for no other reason than the prodigious mass of his published writings, George Sarton would be an outstanding figure in the world of learning. But voluminous output in itself is no criterion of merit. Sarton's distinction is that his colossal achievements—his 'Introduction to the History of Science' alone runs to some 5000 closely printed quarto pages—maintain throughout a very high standard of careful scholarship. The present book is no exception. It deals with Renaissance appreciation of ancient and medieval medicine, natural history, mathematics, and astronomy in the period 1460–1600.

An important point is made early in the book, namely that the flood of Renaissance editions of old medical and scientific treatises was not inspired by curiosity or disinterested scholarship,

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but by utilitarian ends. In general, the reputation of ancient and medieval authorities was so high that more attention was paid to the establishment of accurate texts than to consideration and criticism of their subject-matter. The typical Renaissance approach to science was in fact 'a literary and wordy approach instead of being experimental', though there were a few bold and independent spirits such as Palissy, Paracelsus, and Petrus Severinus.

In the medical section, Sarton deals with the reception of the works of Hippocrates, Celsus, Soranos, Galen, the early Byzantine physicians, and Avicenna, the last named retaining his position of authority in spite of an anti-Oriental spirit shown by medical humanists of the time. In the section on natural historians, Aristotle, Theophrastus, Dioscorides, and Pliny receive most attention, while in that on mathematics and astronomy the principal names, as we should expect, are those of Plato, Aristotle, Euclid, Archimedes, Apollonius of Perga, and Ptolemy.

The book is fully documented, with about forty pages of notes, and there is a good index. The text is bursting with information and enlivened from place to place with characteristically Sartonian comments and judgments.

E. J. HOLMYARD

HISTORY OF SCIENCE

An Illustrated History of Science, *by F. Sherwood Taylor, illustrated by A. R. Thomson. Pp.* xii + 178. *William Heinemann Limited, London.* 1955. 25*s. net.*

This is a most attractive book—one that scientists will buy for presentation and then find they cannot part with. But its appeal will reach a much wider public than a purely scientific one: it is so delightfully written and illustrated that everybody interested in the history of what has become the major factor in modern civilization may well find the book irresistible. The text, which is based on the Christmas lectures given by the late Dr Sherwood Taylor at the Royal Institution in 1952, outlines the history of science from the earliest times to the present day: not as a *tour de force* of desiccated compression but as a lively narrative centring round the fundamental experiments of natural philosophy. At the lectures themselves, these experiments were demonstrated as nearly as possible in their original fashion, and to compensate for the loss of this visual aid the author had the happy idea of illustrating the book with realistic pictures. He was taking a big risk, for there have been many awful warnings of the grotesque distortions inflicted by artists on scientific history. Fortunately the risk was justified, for Mr Thomson's drawings interpret their subjects with perceptive skill and are wholly admirable: those of Leeuwenhoek and Lavoisier deserve special mention, but the standard throughout is excellent.

This combination of a readable and authoritative text with illustrations sympathetically conceived and executed makes the book something novel in the literature of the history of science: it certainly deserves a great success and will doubtless achieve it.

E. J. HOLMYARD

MARS

Physics of the Planet Mars, *by Gerard de Vaucouleurs. Pp.* 365. *Faber and Faber Limited, London.* 1954. 50*s. net.*

Mars is of special interest because it is the only planet possessing an atmosphere whose surface can be seen, and because changes are observed to occur in the delineation of the greenish surface markings, which can plausibly be accounted for on the hypothesis that these areas are covered with vegetation akin to the lichens that grow on the Earth. In addition, the seasonal growth and disappearance of the polar caps and the frequent cloud formations provide evidence of water on Mars.

This book contains a very complete account of observations on the physics of Mars published during the last forty years or so, together with a critical analysis of them. It is divided into five parts. Part I deals with the atmosphere of Mars, its composition, structure, and pressure, and the cloud formations. Part II deals with Martian climatology and temperature; Part III with the polar caps and water on Mars; and Part IV with the surface details and their interpretation. The internal constitution of Mars is discussed in Part V, which is followed by a general summary and conclusion. A comprehensive bibliographical list of references and subject and name indexes complete the volume.

Such a comprehensive account of Martian phenomena has never previously been published. It is a valuable source of information on all matters relating to Mars and will be most useful for reference purposes.

The least satisfactory part of the book is the reproduction of various photographs of Mars, which are of very poor quality and fail to show much of the detail shown in the originals.

H. SPENCER JONES

THE POLAR AURORA

The Polar Aurora, *by Carl Störmer. Pp.* 437. *Oxford University Press, London.* 1955. 55*s. net.*

The aurora has close connections with important types of ionospheric irregularity, so that a book on this subject finds an appropriate place in this series of international monographs on radio. The most authoritative voice in the field of aurora during the past fifty years has been that of Carl Störmer; it is a considerable achievement on the part of the editors of this series to have persuaded Professor Störmer to write this book, and a great achievement on the part of the author, who is now over 80 years old, to have brought the book to a successful conclusion.

Observation and theory are considered in about equal measure. Observational work is first dealt with in detail—auroral forms, and visual and photographic measurement of height and position and of spectrum measurement. Among other items considered are the rather inconclusive results so far obtained in various attempts to use radar methods in auroral study. Some auroral statistics are given, though in general this is the aspect of the subject to which the author gives relatively least weight.

Störmer's classical work on the trajectories of electric corpuscles in a magnetic field naturally dominates the second part of the book. In a separate chapter he describes the application of this theory to cosmic rays. The author discusses in detail those features of aurora which the theory can and cannot explain, and refers to the alternative theories of Chapman and Ferraro, Martyn, Alfvén, and others. The complexities of the aurora are such that the author foresees a complete solution only in the distant future.

This book will undoubtedly be for many years the standard reference book on the aurora. Its publication is timely, as it will give many auroral workers intending to take part in the International Geophysical Year a ready means of familiarizing themselves with the subject.

D. H. McINTOSH

FRONTIERS OF ASTRONOMY

Frontiers of Astronomy, *by Fred Hoyle. Pp. xvi + 360. William Heinemann Limited, London.* 1955. 25*s. net.*

Forty years ago the question whether the objects known as spiral nebulae were members of our Galaxy or were extra-galactic objects was still undecided. Modern large telescopes have provided the answer, and information has been obtained about the distances, sizes, spatial abundance, and line-of-sight motions of these objects, leading to the conception of the expansion of the Universe, the interpretation of which is not at all clear.

Coming nearer home, there is much that is still not yet understood; for instance, the nature of the interior of the Earth, the cause of the ice ages, the origin of the lunar features, the structure of the planets, the origin of the solar system, the nature of cosmic rays. On all these matters there are new and interesting theories. The discovery by Baade by the two different stellar populations has given a new orientation to many fields of stellar investigation, while views about stellar evolution appear to be taking definite shape.

Hoyle has attempted the big task of giving an account of all the various developments which are the growing points in astronomy. Commencing with the Earth, he goes outwards to the Moon, the planets, the Sun, and the individual stars. Our own Galaxy is then considered, leading to galaxies in general, their formation and evolution. Finally he discusses the expansion of the Universe and the alternative explanations of the initial explosion theory and the steady-state theory, the latter entailing the hypothesis of the continuous creation of matter.

There is much, of course, that is still uncertain, and where differing views are held they are presented fairly, though not unnaturally it is sometimes clear where the author's preference lies. The book is intensely stimulating and should be read by all who wish to learn about the current trends in astronomical thought.

H. SPENCER JONES

WOLFGANG GAEDE

Wolfgang Gaede, *by Hannah Gaede. Pp. viii + 127. Verlag G. Braun, Karlsruhe.* 1955. DM. 5.80 *net.*

The creation of a vacuum, generally a high vacuum, is a necessary condition for practically all experimental research concerned in modern investigations of the ultimate structure of matter and is fundamental for what may be called the light electrical industry and for nuclear power. The modern vacuum pump, as distinct from the old cylinder pump or the tedious hand-operated mercury pump, is the creation of Wolfgang Gaede. From the time when, at the age of twenty-seven, he designed his rotary mercury pump and, a little later, his box pump, he originated a series of pumps on new principles, in particular the molecular pump and the diffusion pump, based, in all instances, upon deep theoretical knowledge, clear physical insight, and a genius for design.

The present book is by his devoted younger sister, who was his playmate in childhood and his confidante and companion throughout his life, for he never married. It gives an account of his life from his birth at Freiburg in 1878 to his death in 1945 and, naturally, has much to say of the work which was his passion. He apparently sought neither fame nor riches, but only to pursue the discoveries in which his great powers found expression. He was, however, no recluse: he loved walking and sailing small boats with others, and was an accomplished violinist.

The last years of Gaede's life make a sad story. He lost all the money that he had made by his inventions in the catastrophic inflation in Germany of 1923, but became an inspiring university professor and with great success continued his work on the production and measurement of high vacua. In 1933, the year in which he was awarded the Duddell Medal in London and the Siemens Ring in Berlin, he was denounced by Nazi personalities as politically unreliable and friendly to Jews, and was removed from his university post—he was, indeed, threatened with prosecution. Of his examination by the political powers he said that at the time he had the feeling '*entweder sei er verrückt geworden oder die anderen seien verrückt.*' He was shamefully treated but able to continue his work in a private laboratory, which was totally destroyed by bombs in 1944. In the following year he died of diphtheria and undernourishment.

The book is beautifully written and gives a vivid account of life in cultivated German circles before the end of the old European civilization in 1914, and an intimate picture of a rare inventive genius and a man of great character.

E. N. DA C. ANDRADE

PHYSICS AND MICROPHYSICS

Physics and Microphysics, *by Louis de Broglie, translated by M. Davidson. Pp.* 286. *Hutchinson's Scientific and Technical Publications, London.* 1955. 21*s. net.*

Louis de Broglie, the founder of wave mechanics, is a lucid and inspiring speaker on themes concerned with physics as a branch of learning rather than as a branch of technology, and the present book is a collection of lectures and expositions, some seventeen in number, mostly on such themes. They were, clearly, delivered to different types of audience at different periods, at least one before the invention of the atomic bomb; it would have been of interest to know the date and occasion of each address, which is given in only two cases.

The title refers to the physics of ponderable bodies, in the ordinary sense, which is often called classical physics, where continuity and certainty reign, and to the physics of ultimate particles and wave packets, where quantum theory and uncertainty prevail. Most of the book, however, deals, as might be expected, with microphysics, in particular with matters in which wave mechanics plays a prominent part, physics being here that which has been superseded. Thus the first chapter, evidently written more than ten years ago, deals chiefly with the wave mechanical theory of the electronic structure of the atom in simple style, and the second chapter with much the same subjects in rather more detail. There is, in another chapter, a somewhat more technical treatment of the formation of images in corpuscular optics, bearing on the possibilities of the electron microscope and leading to the conclusion that we can never see, in the microscopic sense, the structure of atomic edifices. These chapters, with a few shorter addresses on related subjects, form the first part of the book.

A second part, labelled not altogether appropriately 'scientific philosophy', contains the longest and most personal articles. One, entitled 'Revelations of Microphysics', deals with the fundamental implications of the quantum theory, in particular with the uncertainty principles and the disappearance of the individuality of the corpuscle, with its bearing on determinism. Another begins with the author's personal memories of the start of wave mechanics and then proceeds to consider the problems of the nuclear field, discussing very difficult subjects with a masterly simplicity of style. The chapter most nearly approaching academic philosophy is one on Bergson's conceptions, which are presented in abbreviated form, as are in most cases the less significant chapters on the history of the sciences that conclude the book.

E. N. DA C. ANDRADE

NUCLEAR SHELL STRUCTURE

Elementary Theory of Nuclear Shell Structure, *by M. G. Mayer and J. H. D. Jensen. Pp.* 269. *John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 62*s. net.*

For many years it was believed that nothing existed in nuclear physics comparable with the essentially simple structure of the atom as reflected in the periodic system of the elements. By 1948, however, the accumulation of precise data indicated clearly that there does exist a nuclear shell structure very like a periodic system for nuclei. Independently, Mayer in America, and Haxel, Jensen, and Suess in Germany, found the explanation for it. Since then, the 'nuclear shell model' has had great success in correlating experimental material.

The appearance of a book by Mayer and Jensen, the two main originators of the theory, is therefore to be welcomed. In it the experimental evidence pointing to nuclear shell structure is lucidly marshalled, followed by a simple explanation in terms of nuclear orbitals, in which the coupling between spin and orbital motion in nuclear dynamics plays an important role; there is a detailed discussion of empirical nuclear systematics in the light of the theory. Beyond this the book is disappointing. It lacks a coherent plan of subject matter. The authors have attempted to say a little about many topics of nuclear physics. Often they seem unaware of important contributions to the subject. Indeed, the book is marred by a defect common to many publications from America, namely, ignoring almost all work which has not been published in the *Physical Review*, and even from that the omissions are many. Not only are references to original sources very incomplete, but the authors are careless about such details as the spellings of names and the definition of physical quantities. The printing of mathematical formulae is ungainly, and the quality of the illustrations is very mixed—some are very clear, others succeed only in confusing the point that should be illuminated.

M. H. L. PRYCE

NUCLEAR SCIENCE

Annual Review of Nuclear Science, Volumes III and IV. *Pp. x* + 412 *and x* + 483. *Annual Reviews Inc., Stanford, California, in co-operation with the National Research Council of the National Academy of Sciences.* 1953 *and* 1954. $7 *net per volume.*

It is one of the minor oddities of nuclear physics that of its two annual publications the 'Progress in Nuclear Physics' contains review articles, while the 'Annual Review of Nuclear Science' contains mainly progress reports. The policy of the new editors who are responsible for these two issues of the latter publication is that they should cover several years; in the first two issues many articles took rather too literally the idea of being an annual review. This is all to the good, for even a subject developing as rapidly as nuclear science does not lend itself to an annual stocktaking in every one of its branches.

The amount of research done in nuclear science today is remarkable, and the articles in these issues—few of which have fewer than fifty references and one has nearly six hundred—bear this out. But the quality of research varies, and many of the articles overwhelm the reader with an avalanche of facts, theories, and results without any attempt at their critical evaluation. Where such criticism is exercised and the work reported is set, however briefly, against the background of previous work, the articles are all that can be desired.

There are few branches of nuclear science that are not touched upon, and although the general production is excellent the volumes could be made even more informative to the non-specialist who likes to read an article without continually looking up references at the back by quoting references by author and year rather than by number. About half of each volume deals with nuclear physics, experimental and theoretical, and the rest is given over to nuclear chemistry, biology, medicine, and even geology. Here could be, and indeed often is, a means for broadening the scientist's mind.

L. R. B. ELTON

BOLTZMANN'S LAW

Boltzmann's Distribution Law, *by E. A. Guggenheim. Pp.* 61. *North-Holland Publishing Company, Amsterdam.* 1955. 5*s.* 6*d. net.*

It is a pleasure to review a book as short, elegant, useful, and inexpensive as this one. Many teachers of physics and chemistry must have regretted the fact that the simple bases of statistical thermodynamics are usually buried in a mass of mathematical detail, or arrived at only as an apparently irrelevant 'interpretation' at the end of an exposition of classical thermodynamics. Professor Guggenheim's book cuts right across the traditional line of approach by introducing Boltzmann's distribution law as an axiom for discrete energy states, thus defining temperature implicitly, and proceeding on this basis, expressions are derived for a number of bulk properties. No formal statement of thermodynamic laws is made, and entropy is not mentioned.

The topics discussed in detail include monatomic and diatomic gases, simple crystals, the dielectric constants of gases, and chemical equilibrium in gases. In every case the exposition is clear, important qualitative points are emphasized, and numerical values are given to impress upon the reader the orders of magnitude involved. Only an elementary knowledge of calculus is presupposed, and the preface describes the book as suitable for students in their first term at a university. It might be profitable to wait a little longer, so as to provide a basis of rather more experimental knowledge, but there is no doubt that the book can be read with profit at an early stage in a student's career, and our thanks are due to the author and to the publisher for producing so good an exposition at such a reasonable price.

R. P. BELL

NUCLEAR RADIATION DETECTORS

Nuclear Radiation Detectors, *by J. Sharpe. Pp.* 179. *Methuen and Company Limited, London.* 1955. 11*s.* 6*d. net.*

This little monograph is concerned with a very wide field, since it embraces within its scope almost the whole field of modern radiation detectors as applied in nuclear physics and allied subjects. Indeed, the main question that arises in reading the book is concerned with this point. Opinions will differ as to the wisdom or otherwise of choosing to condense the whole subject within a single monograph.

If the reader accepts the fact that space is definitely limited in treating the enormous amount of material available, then he can have little complaint with the present volume. There is a veritable mine of information stored within its pages.

The subject matter is subdivided in a novel manner. It falls within five main chapter headings, namely the interaction of nuclear radiation with matter, detection media, efficiency of detectors, secondary emission and scintillation counters, and ionization devices. It is a logical arrangement of the subject and one that leads naturally to a step-by-step approach to the more complex devices. It is notable that scintillation counters precede ionization types—this is probably fully justified in view of the very wide versatility of the scintillation type as compared with the Geiger or proportional types. Many of the less universal counters are discussed, for example conduction counters and gridded ion-chambers receive attention.

As an introduction to a very important field the work can be highly recommended. Students should find it a profitable investment at its modest price. Those wishing or requiring more extended treatments will find that their needs are anticipated by the very extensive bibliography. S. C. CURRAN

IONOGRAPHY

Ionography, *by H. J. McDonald. Pp. x + 268. The Year Book Publishers Inc., Chicago; Interscience Publishers Limited, London.* 1955. 48*s. net.*

Ionography is the term suggested by the author for the processes of electromigration of substances in media stabilized by paper, agar, or similar materials. Although not a new technique, the resurgence of interest in the method in the last few years has made it difficult for the newcomer to select from the multiplicity of designs the apparatus best suited to his needs, and details of specific applications have to be sought in an ever-widening range of journals. To help both the newcomer and the more experienced worker Professor McDonald and his collaborators have attempted to bring together in this book the available information on the theory, technique, and applications of the ionographic method. The emphasis is on paper-stabilized systems, although the use of other stabilizers is also reviewed. The result is a very readable account which undoubtedly owes much to the fact that the author is drawing largely on his own experience, particularly in the chapters dealing with mobility measurements. Pictures of actual separations have wisely been omitted, as they seldom gain in reproduction, but a number of well chosen diagrams and graphs illustrating specific points have been included. In the chapters dealing with applications the author and his collaborators have extracted the salient points from key papers and summarized them in a readable and informative manner. There is a very full bibliography citing papers up to 1954. One has the impression that much critical thought has gone into the preparation of this book, which should be of interest to all those wishing to make full use of this very powerful technique either for analytical purposes or for fundamental mobility studies.

A. J. WOIWOD

ORGANIC SYNTHESES

Organic Syntheses, Collective Volume III, *edited by E. C. Horning. Pp. x + 890. Chapman and Hall Limited, London; John Wiley and Sons Inc., New York.* 1955. 120*s. net.*

Volumes of 'Organic Syntheses' are automatically consulted by the present generation of organic chemists whenever there is need to prepare in bulk in the laboratory a compound that cannot easily be purchased: consequently the latest addition to this series needs no introduction to its potential readers. The separate small volumes appear on library shelves with such regularity that it is hard to realise that it is now twelve years since Collective Volume II was published.

Volume III, in consequence, collects together publications of several years, and so the editor has taken care to correct and modernize the text, adding literature references up to 1952. Throughout the book can be found additional notes, giving valuable practical hints, submitted by those who have had occasion to repeat its preparations. In addition to the usual comprehensive indexes to the compounds described and to the reactions involved, the editor has added a further, most useful, index to the methods of preparation and purification of important organic solvents and of special inorganic reagents—as for instance ozone, sodamide, and active nickel, platinum, and palladium catalysts.

While everyone will be sure to regard some of the preparations as curiosities of little intrinsic value, nearly everyone will also find in this volume just that time-saving route to that crucially important substance which he himself needs, or at least the cognate preparation from which a required synthesis can speedily be developed.

W. A. WATERS

CATALYSIS

Catalysis, Volume II: Fundamental Principles, Part 2, *edited by Paul H. Emmett. Pp. vi + 473. Reinhold Publishing Corporation, New York; Chapman and Hall Limited, London.* 1955. 94*s. net.*

This second volume of a lengthy cooperative work contains six chapters. The first is a valuable, concise account of very many reactions of gases and vapours, and the catalysts effective for them, discussed from the industrial point of view. The next deals with diffusion and reaction rates in the pores of catalysts, and suggests how pore structure might regulate what reactions are catalysed by porous substances. The next three chapters give brief accounts of some properties of solids—magnetic, electrical conducting and semi-conducting properties, the filling of electronic levels, and lattice dislocations—all of which might conceivably influence catalytic power but whose functions for catalysis, if any, are uncertain. Theories of reaction rate are given in some detail, but only a small part of them deals with reactions at surfaces. Adsorption is discussed at length in this volume, as in the first—even physical adsorption, which is admitted to have little to do with catalysis. There is, however, little detailed account of the structure of chemisorbed layers and still less of how such layers facilitate reactions which do not occur in their absence. There is, however, quite a good discussion of apparent variations in adsorptive power on different parts of a surface. These chapters give the impression of trying to mention everything which might conceivably have a connection with catalytic power, and to record many different suggestions, rather than to appraise these suggestions critically in relation to why catalysts work. A more selective and critical treatment might have been more illuminating, as well as less expensive to print; most readers are likely to emerge from these 170 pages with little enlightenment as to what general principles govern catalysis at surfaces.

The final chapter is more coherent, competently summarizing the theory of several types of homogeneous catalysed reactions; acid-base catalysis is particularly fully described.

Detailed treatment of several

important types of catalysis are promised for later volumes. May we hope that they will be more factual and less discursive, with theory (if any) more directly relevant to catalysis?

N. K. ADAM

ANALYTICAL CHEMISTRY

Analytical Chemistry—The Working Tools. *Edited by C. R. N. Strouts, J. H. Gilfillan, and H. N. Wilson.* Vol. I. *Pp. xxi* + 494; Vol. II. *Pp. ix* + 495–1067. *Oxford University Press, London.* 1955. *£5 5s. net for the two volumes.*

A foreword by the late Sir Wallace Akers states that these two volumes represent 'the collection of analytical techniques and methods which have been standardized throughout the analytical laboratories of Imperial Chemical Industries.' The three editors are members of an Analytical Chemists' Committee which the Company set up in 1928. Among the functions of this committee has been the critical examination of methods and techniques with the objects of maintaining a degree of standardization throughout the Company and of substituting new procedures for old ones wherever this seemed desirable. This is no encyclopaedic collection of works methods used throughout a large organization, but a comprehensive treatise on the art and science of chemical analysis.

The fifteen chapters of Volume I cover accuracy, manipulation, sampling, weighing, calibration and use of volumetric apparatus, measurement of temperature and pressure, measurement of density and specific gravity, determination of crystallizing point and melting point, distillation and the determination of distillation range, reagents and indicators, determination of *p*H, standardization of volumetric solutions, quantitative ultimate organic analysis, quantitative organic microanalysis, and gas analysis.

The nine chapters of Volume II cover potentiometric titration, conductometric analysis, polarography, electrodeposition, introduction to colorimetric analysis, ultra-violet and infra-red absorption spectrophotometry, emission spectrography, X-ray spectrochemical analysis, X-ray diffraction, chromatography, and application of statistical methods to chemical analysis.

The material of the first eight chapters can hardly be called new, but there can be absolutely no doubt as to the need to re-state it. It all bears the stamp of experience: one is struck also with the lucidity of the theoretical sections. The sections on quantitative ultimate organic analysis and on organic microanalysis are comprehensive and authoritative. Techniques of gas analysis, with which the first volume ends, are treated in a similarly comprehensive way.

It is in Volume II that the more recent developments appear, in which some physical property other than mass is usually measured. Most valuable of all, perhaps, is the frequent final assessment of a technique under the heading 'Uses and Limitations'. In the main it is the technique and, often in some considerable detail, the principles underlying it, to which most attention is given. It might be objected that much of this information exists elsewhere, but the inclusion is probably justifiable. In this section more of the practical examples are given of the application of the techniques, e.g. of ultra-violet absorption spectroscopy to quantitative analysis. The examples are chosen from the Company's experience.

The treatment in Volume II is a little uneven: the discussion on the uses of X-ray powder diffraction, for example, does not perhaps sufficiently indicate the outstanding value of this technique in inorganic analysis. More references to the work of Rooksby, who has been active in this field for over twenty-five years, would have emphasized this point. The chapter on emission spectrography includes only a short mention of flame excitation. In this, and in the omission of any treatment of vapour phase chromatography, the book might be said to be not quite up to date, but this clearly results from the time needed to collect, edit, and publish such a wealth of information.

The book will be of the greatest value to all analysts; if it serves also to convince young graduates that a worthwhile career is open to those of them who can accept the discipline of analysis, Imperial Chemical Industries will have done a great service.

R. C. CHIRNSIDE

CHEMISTRY OF MICRO-ORGANISMS

The Chemistry of Micro-organisms, *by A. Bracken. Pp.* 343. *Sir Isaac Pitman and Sons Limited, London.* 1955. *30s. net.*

The compounds found in cultures of micro-organisms after growth on simple substances, such as sugars and ammonia or amino-acids, are numerous and have interested chemists and biochemists for many years. This book provides a survey of such substances and should be very useful to chemists, as it gives a full treatment of the chemistry of microbial products as well as an introduction to microbiology.

As a background to the main subject the early chapters deal briefly with the biology of bacteria, yeasts, and moulds as well as with the mechanism of enzyme action. The examples illustrating the main points are well chosen and of general interest. The book deals mainly with the extracellular products found in cultures of micro-organisms (particularly moulds), but some attention is given to the phenomenal synthetic powers of these organisms, many of which can build up complex cell components such as nucleic acids and proteins from ammonia and sugars or even carbon dioxide. The use made of micro-organisms in the commercial production of antibiotics, solvents, citric acid, vitamin B_{12}, and other compounds is described in some detail. Considerable attention is given to the research which led to the discovery and exploitation of penicillin, streptomycin, and other antibiotics; their chemistry also is considered in detail. A large part of the book deals with the isolation and identification of microbial pigments and of the numerous aromatic, aliphatic, and heterocyclic substances found in cultures of moulds. It seems that more is known of the chemistry of these substances than of the biochemical mechanisms which lead to their formation.

A concluding chapter provides practical details of simple microbiological techniques such as the isolation and maintenance of pure cultures; this information should be valuable for the chemist wishing to handle micro-organisms. Finally, some unsolved problems in microbiology are discussed, including the mode of action of antibiotics and the mechanism of the Gram stain.

The value of this book for reference purposes is increased by an extensive bibliography and a full index.

JUNE LASCELLES

AUTOTROPHIC BACTERIA

Biochemistry of Autotrophic Bacteria, *by H. Lees. Pp. viii* + 112. *Butterworths Scientific Publications, London.* 1955. *21s. net.*

The biochemistry of the autotrophic bacteria is still far from understood, but is a subject which would be well served by a critical concise monograph suitable for honours students. Unfortunately this volume presents an uneven, and sometimes superficial, discussion of present work; furthermore, it does little to relate present problems to those current in other fields of biochemistry. For example, no reference is made to the tricarboxylic acid cycle in connection with the fixation of carbon dioxide by heterotrophs, whereas the more recent, and perhaps less well established, Calvin photosynthetic cycle is given prominence. Ideas are briefly introduced but not always precisely stated. Thus the concept of a 'closed system' is introduced in one line of text and dismissed in one footnote. The author may have attempted to make the book appear comprehensible to an intelligent layman, but he has detracted much from its value to the student.

The major portion of the book is devoted to a brief description of the main groups of autotrophs; the non-photosynthetic sulphur bacteria, the hydrogen and nitrogen bacteria, and the photosynthetic bacteria. Here also the treatment is uneven; for example, Larsen's recent work with *Chlorobium* spp. is given in detail, but too little information is given about the better known purple photosynthetic bacteria.

There are some errors of fact. It suffices to awaken the unwary by calling attention to a few, such as the unusual definition of cytochromes on page 17; the statement on page 74 that thioctic acid affects photosynthesis, when in fact the quinone reaction was studied; and the omission of any reference state for the free-energy data given throughout the book.

C. P. WHITTINGHAM

A. I. VIRTANEN

Biochemistry of Nitrogen. A Collection of Papers on the Biochemistry of Nitrogen and Related Subjects. Dedicated to A. I. Virtanen on the Occasion of his 60th Birthday. (*Editorial board; N. J. Toivonen, E. Tommila, J. Erkama, P. Roine, and J. K. Miettinen.*) *Pp.* 535. *Suomalainen Tiedeakatemia, Helsinki.* 1955. *Bound*, $12 *net*; *paper cover*, $10 *net.*

This collection of papers published in honour of the distinguished Finnish biochemist A. I. Virtanen contains 49 contributions on biochemical topics of current interest. The subjects include the biochemistry of amino acids, proteins, nucleic acids, porphyrins, nitrogen fixation, photosynthesis, and nitrate reduction. The field covered is rather wider than the title of the book suggests. Among the contributors are E. J. Bigwood, R. H. Burris, A. Butenandt, M. Calvin, E. B. Chain, H. von Euler, C. Fromageot, G. Hevesy, C. N. Hinshelwood, F. Lynen, L. Pauling, H. Staudinger, J. B. Sumner, H. Theorell, A. Tiselius, A. R. Todd, O. Warburg, and many other leading biochemists. While some of the articles are general reviews, like those of Todd on the synthesis of nucleotide coenzymes, Hinshelwood on mutations and adaptations in bacteria, and Staudinger on macromolecules in biology, the majority are reports on new experimental work. The book gives a fascinating cross-section of current biochemistry.

H. A. KREBS

CHEMISTRY OF ENZYMES

Outlines of Enzyme Chemistry, *by J. B. Neilands and Paul K. Stumpf. Pp. x +* 315. *John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1955. 52*s. net.*

As its title suggests, this book is an outline of enzyme chemistry, but one which will be best appreciated by students already grounded in chemistry and physiology. Devoid of detail and clear in expression, it allows an overall view of enzymology to be easily and rapidly obtained.

Throughout the book the authors are consistent in their efforts to treat main concepts with brevity but not with obscurity, and at the same time to provide carefully selected references to extend their text. This method of presentation, perhaps a consequence of its origin from lecture material, makes the book easily assimilable. From an instructive viewpoint it is effective because points are amply illustrated by actual experimental data, by practical details, or by application of a principle under discussion to definite cases.

The first two parts of the book, which most students of biochemistry should relish, deal very adequately with the isolation and characterization of enzymes and the physicochemical aspects of their behaviour. The two remaining parts—'types of coenzymes and enzymes' and 'metabolic patterns'—do not flow as smoothly as the others, perhaps because of the nature of the material and the rigour of the condensation. The final chapter, by R. Stanier, deals most stimulatingly with the contributions made by microbiology to an understanding of the mechanism of enzyme synthesis.

This book will give students commencing the study of biochemistry a clear conception of the physical principles so often used in studies of enzymes, and will certainly show them how meagre is our knowledge of enzyme behaviour and how vast are the opportunities for attack upon this problem by physical and other means.

J. R. P. O'BRIEN

CALANUS FINMARCHICUS

The Biology of a Marine Copepod, *by S. M. Marshall and A. P. Orr. Pp. vii +* 188. *Oliver and Boyd Limited, London.* 1955. 21*s. net.*

In 1770 Bishop Gunnerus of Nidaros (Trondheim) named a small crustacean taken from the sea off northern Norway. He called it *Monoculus finmarchicus*, including it in the Insecta Aptera established by Linnæus. That was the initial recognition by science of perhaps the commonest of marine animals which is a major food of pelagic fishes, including the herring, and of certain whales. The structure, physiology, life history, and habits of *Calanus finmarchicus*, as it is now called, are matters of major interest to all concerned with marine biology and fishery research. For the past thirty years *Calanus* has formed the main subject of research of the two senior members of the staff of the laboratory of the Scottish Marine Biological Association at Millport. In this book these workers have gathered together the fruits of their own labours and of all others who have studied *Calanus*: in so doing they have produced the first comprehensive account covering all aspects of the life of a marine copepod crustacean. Admirably produced, this book is a credit to both authors and publisher; it is a major addition to the literature of marine biology and of the Crustacea.

C. M. YONGE

BIRDS OF SAURASHTRA

Birds of Saurashtra—India, *by R. S. Dharmakumarsinhji. Pp.* 561. *Published at Dil Bahar, Bhavnagar, Saurashtra, by the author.* 1955. £5 12*s.* 6*d. net.*

A consequence of the British leaving India was a decline in ornithology, since in the past nearly all research on Indian birds was carried out by Englishmen, with the recent important exception of Salim Ali. A regional survey by another Indian ornithologist is therefore most welcome. The interest of this book is primarily local. Saurashtra, the peninsula between the Gulfs of

Kutch and of Cambay, has a rich variety of shore and marsh birds; much of the inland country is dry and scrubby, but the Gir forest brings in many woodland forms. The book is primarily devoted to a description of each species, its distribution, general habits, and nesting; most of it is based on original observations, and it gives an impression of enthusiasm, competence, and reliability. There is a very short and somewhat naïve descriptive introduction. The coloured plates by Somalal Shah are sufficient for identification but are grouped with little regard for size, while related species are sometimes placed far apart. The author's valuable photographs record both behaviour and species not previously photographed. Its ample size, production, and price recall English bird-books before 1914, and suggest that it will be found chiefly in rich men's libraries. D. LACK

PRIMATES

Primates, *by W. C. Osman Hill.* Part 1—Strepsirhini. *Pp. xxiii* + 798. Part 2—Haplorhini. *Pp. xx* + 347. *University Press, Edinburgh.* Part 1, 1953, £5 5*s. net.* Part 2, 1955, 63*s. net.*

To present, in detail, for every genus of the Primates, all that is known of the external characters, the skeleton, skull, dentition, musculature, viscera, behaviour, and distribution, is the basic aim of the survey of the Primates which Dr Osman Hill has undertaken. Already in the two volumes so far issued (on living and fossil Lemurs, Lorises, and Tarsioids) we can fully appreciate the valuable service that the author is rendering to specialists in Primatology and to many others—zoologists, palaeontologists, and anthropologists. He does more than provide a thorough catalogue of the primate genera; he has in addition taken great pains to present comprehensive definitions and specifications of all the important taxonomic categories at every level of the Primate hierarchy, Ordinal, Sub-ordinal, Familial, and Generic. These clearly written and well arranged sections of the compendium constitute in themselves a considerable contribution to the comparative anatomy and taxonomy of the Primates, even though there will be serious disagreement about some aspects of Dr Hill's classification. Thus at the outset, in deciding what constitutes a Primate, he finds no reason to go beyond the dicta of Mivart (1873), and accordingly omits the tree-shrews from the Order. There is practically no discussion of this decision, and indeed, to say that the Order 'has to be stretched almost beyond recognition' to accommodate the Tupaioidea verges on hyperbole; the exclusion of the tree-shrews robs the work of some of its usefulness as a guide to the whole evolution of the Primates. He again diverges widely from usual practice in following Pocock (1918) and promoting the Tarsioids from their 'prosimian' status into alliance with the Anthropoidea to form the Haplorhine, as distinct from the Strepsorhine, Grade. The intermediate and complicated position of the Tarsioids between Lemuroidea and Anthropoidea does of course leave room for genuine difference of taxonomic opinion, though phylogenetically it is probably true that all schools recognize the Tarsioids as following a distinctive line of development from an ancestry not far from the Basal Primate stock. Indeed, what is meant by a 'tarsian' or 'tarsioid' ancestry for the Anthropoids has never been made very clear. Dr Hill does not say much on this problem, but this is perhaps understandable, since extensive controversial discussion would mar a work of this sort. One point to be mentioned is the absence in the second volume of reference to the highly important work by Carpenter and by Hebb on anthropoid behaviour and mental development, and one hopes that this omission will not persist in subsequent volumes on the Anthropoidea or Hominoidea. Both the newly issued volumes, beautifully produced, give every promise that Dr Hill, when he has completed his task, will have provided what has been needed for some time: an up-to-date, well informed, well illustrated, and well documented source book of the Primates.

J. S. WEINER

TSETSE FLIES

The Natural History of Tsetse Flies (London School of Hygiene and Tropical Medicine Memoir No. 10), *by P. A. Buxton. Pp. xx* + 826. *H. K. Lewis and Company Limited, London.* 1955. 84*s. net.*

This is a large volume, but not because the author is prolix but because it summarizes an immense body of work mostly carried out in Africa in the last fifty years. It is written in an exceptionally lucid style, free from all but the essential technical terms. It is very well produced, amply documented, with an extensive index and excellent illustrations. It is almost completely free of misprints. The work is encyclopaedic in conception, and besides discussing every aspect of tsetse biology deals, at least briefly, with such subjects as the climate and vegetation of Africa and the species problem in Trypanosomes. There are many topics on which all entomologists will find it a valuable work of reference. Apart from the importance of tsetse to the health and welfare of man, the book is also an admirable illustration of how a large and complex biological problem can be tackled in the field.

The author does not in general refer to literature published after the end of 1952. At about that time papers appeared of great importance to two chapters in the book. It is probable that the attempts to relate tsetse populations to climate should be reconsidered. The numbers of flies form a series with an internal correlation, and this greatly complicates any attempt to analyse their relation to climate. The complex correlations between different climatic factors, not all of which have been measured, is a further difficulty. The study of populations by marking and recapture, a method largely developed by students of the tsetse, turns out to be more complicated than was supposed. Bailey (1951–52) has shown that the usual methods involve a bias which at best invalidates tests of significance. There appear to be two topics which could be studied in greater detail in the tsetse fly. One is the cytology, which might well confirm or correct the present taxonomy. The other is the study of fly behaviour by modern methods; it is possible that this would make it easier to understand the process of habitat-selection. O. W. RICHARDS

Some books received

(*Note.* Mention of a book on this page does not preclude subsequent review.)

BIOLOGY

The Cytology and Life-History of Bacteria (*second edition*), *by K. A. Bisset. Pp. xii* + 164. *E. and S. Livingstone Limited, Edinburgh and London.* 1955. 25*s. net.*

School Nature Study, Volume 50, Nos. 198–201. The Journal of the School Nature Study Union. *Headley Brothers Limited, London. Annual Subscription* 10*s. net.*

Some Aspects of Life in Fresh Water, *by E. J. Popham. Pp viii* + 123. *William Heinemann Limited, London.* 1955. 6*s. net.*

Traité de Paléontologie, Volume 5. Amphibiens, Reptiles, Oiseaux, *edited by J. Piveteau. Pp.* 1113. *Masson et Cie, Paris.* 1955. *Paper covers, Fcs.* 12 000; *bound, Fcs.* 12 800 *net.*

BOTANY

The Annual Report of the Agricultural and Horticultural Research Station (The National Fruit and Cider Institute), Long Ashton, Bristol, 1954. *Pp.* 207. *University of Bristol,* 1955. 15*s. net.*

CHEMISTRY

Biochemical Preparations, Volume 4, *edited by W. W. Westerfeld. Pp. vii* + 108. *John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1955. 30*s. net.*

Catalysis, Volume 3, *edited by P. H. Emmett. Pp. vii* + 504. *Reinhold Publishing Corporation, New York; Chapman and Hall Limited, London.* 1955. 100*s. net.*

Cole's Practical Physiological Chemistry, *by E. Baldwin and D. J. Bell. Pp. x* + 263. *W. Heffer and Sons, Cambridge.* 1955. 21*s. net.*

Cosmologie et Chimie, *by A. Dauvillier. Pp. viii* + 215. *Presses Universitaires de France, Paris.* 1955. *Fcs.* 900 *net.*

Hydrogen Ions, Volume 1 (*fourth edition*), *by H. T. S. Britton. Pp. xix* + 476. *Chapman and Hall Limited, London.* 1955. 70*s. net.*

Rechentafeln zur Chemischen Elementar-Analyse, *by R. Krzikalla. Pp.* 232. *Verlag Chemie G.m.b.H., Weinheim/Bergstr.* 1956. *DM* 12 *net.*

Spectrochemical Abstracts, Volume 4, 1946–1951, *by E. H. S. van Someren and F. Lachman. Pp.* 179. *Hilger and Watts Limited, London.* 1955. 30*s. net.*

Synthetic Ion-Exchangers, *by G. H. Osborn. Pp. ix* + 419. *Chapman and Hall Limited, London.* 1955. 30*s. net.*

GENERAL

Erlanger Forschungen, Volume 1, Series B: Naturwissenschaften (Johann Gottlob Lehman (1719–1767)), *by Bruno v. Freberg. Pp.* 159. *Universitätsbibliothek, Erlangen.* 1955. *DM* 12.80 *net.*

Fifth Symposium (International) on Combustion. *Pp. xxvi* + 802. *Reinhold Publishing Corporation, New York; Chapman and Hall Limited, London.* 1955. 120*s. net.*

Ludwig Boltzmann, *by E. Broda. Pp. viii* + 152. *Franz Deuticke, Vienna.* 1955. *Paper covers, DM* 9.50 *net; linen, DM* 11 *net.*

Plastics for Corrosion-Resistant Applications, *by R. B. Seymour and R. H. Steiner. Pp. xvi* + 423. *Reinhold Publishing Corporation, New York; Chapman and Hall Limited, London.* 1955. 60*s. net.*

Praktische Edelstein-Prüfung, *by B. W. Anderson. Pp.* 262. *Ruhle-Diebener-Verlag K.G., Stuttgart.* 1955. *DM* 24.60 *net.*

Research Films in Biology, Anthropology, Psychology and Medicine, *by A. R. Michaelis. Pp. xvi* + 490. *Academic Press Inc., New York.* 1955. $10 *net.*

Titanium—Metallurgy of the Rarer Metals, No. 4, *by A. D. McQuillan and M. K. McQuillan. Pp. xix* + 466. *Butterworths Scientific Publications, London.* 1956. 56*s. net.*

GEOLOGY

Stratigraphic Geology, *by M. Gignoux, translated by G. G. Woodford. Pp. xvi* + 682. *W. H. Freeman and Company, San Francisco; Bailey Brothers and Swinfen Limited, London.* 1955. 80*s. net.*

MATHEMATICS

Experimental Design and its Statistical Basis, *by D. J. Finney. Pp. xi* + 169. *Cambridge University Press, London.* 1955. 30*s. net.*

MEDICINE

Basi Teoriche e Sperimentali per una Patogenesi enzimatica dell'Arteriosclerosi, *by A. Cali. Pp.* 107. *Libreria Natale Simonelli Editrice, Perugia.* 1955. *Lire* 800 *net.*

PHYSICS

Errors of Observation and their Treatment, *by J. Topping. Pp.* 119. *The Institute of Physics, London.* 1955. 5*s. net.*

Humidity, *by H. L. Penman. Pp.* 71. *The Institute of Physics, London.* 1955. 5*s. net.*

An Introduction to Reactor Physics, *by D. J. Littler and J. F. Raffle. Pp. viii* + 196. *Pergamon Press Limited, London.* 1955. 25*s. net.*

Introductory Nuclear Physics (*second edition*), *by D. Halliday. Pp. ix* + 493. *John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1955. 60*s. net.*

Les Dislocations et la Croissance des Cristaux, *by W. Dekeyser and S. Amelinckx. Pp. viii* + 184. *Masson et Cie, Paris.* 1955. *Fcs* 2000 *net.*

Low Temperature Physics, *by L. C. Jackson. Pp. viii* + 158. *Methuen and Company Limited, London; John Wiley and Sons Inc., New York.* 1955. 10*s.* 6*d. net.*

Microstructures of Diamond Surfaces, *by S. Tolansky. Pp. viii* + 67. *N.A.G. Press Limited, London.* 1955. 40*s. net.*

Niels Bohr and the Development of Physics, *edited by W. Pauli, L. Rosenfeld, and V. Weisskopf. Pp. vii* + 195. *Pergamon Press Limited, London.* 1955. 30*s. net.*

Nuclear Magnetic Resonance, *by E. R. Andrew. Pp. xi* + 265. *Cambridge University Press, London.* 1955. 35*s. net.*

Nuclear Physics, Volume 1, No. 1, *edited by L. Rosenfeld. Pp.* 72. *North-Holland Publishing Company, Amsterdam.* 1956. *Subscription price for volume* (700 *pages*) 106*s. net.*

Nuclear and Radiochemistry, *by G. Friedlander and J. W. Kennedy. Pp. ix* + 468. *John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1955. 60*s. net.*

Physics of Fibres, *by H. J. Woods. Pp.* 100. *The Institute of Physics, London.* 1955. 30*s. net.*

ZOOLOGY

Soil Zoology (Proceedings of the University of Nottingham Second Easter School in Agricultural Science, 1955), *edited by D. K. McE. Kevan. Pp. xiv* + 512. *Butterworths Scientific Publications, London; Academic Press Inc., New York.* 1955. 55*s. net.*

The Wildfowl Trust, Seventh Annual Report, 1953–1954, *edited by P. Scott and H. Boyd. Pp.* 235. *The Country Life Limited, London.* 1955. 10*s. net.*

Notes on contributors

ALFRED LANDÉ,

Ph.D.,

Was born at Elberfeld, Germany, in 1888, and studied at Marburg, Göttingen, and Munich: he was a pupil of Max Born and Arnold Sommerfeld. From 1920 to 1922 he was Privatdozent at Frankfurt and from 1922 to 1931 professor of physics at Tübingen. Since 1931 he has been professor of physics at Ohio State University. His researches have been on the vector model of atomic structure, spectral lines, the Zeeman effect, and multiplet theory. He is the author of several books on the principles of quantum theory; his present article is based on the Fulbright Lectures he gave in Italy in 1954.

J. W. S. PRINGLE,

Sc.D., M.B.E., F.R.S.,

Was born in Manchester in 1912 and was educated at Winchester and at King's College, Cambridge. In 1938 he became University Demonstrator in Zoology in the University of Cambridge, but in the following year left for war service with the Telecommunications Research Establishment, and subsequently with the Ministry of War Transport. Since 1945 he has been University Lecturer in Zoology at Cambridge and Fellow of Peterhouse. His research has been on the physiology of the nerves and muscles of insects. In 1953 he visited the University of Ceylon as Leverhulme Research Fellow and carried out work on insect song.

A. T. JAMES,

B.Sc., Ph.D.,

Was born in Cardiff in 1922 and was educated at University College School, Hampstead. While working with Kodak Limited he continued his studies at the Northern Polytechnic, London, from which he won a scholarship to University College, London. After some research on antimalarial drugs at Bedford College, London, he carried out at the Lister Institute, with R. L. M. Synge, an investigation of the structure of gramicidin. In 1950 he joined A. J. P. Martin at the National Institute for Medical Research and with him developed the technique of gas-liquid chromatography, which he is now using for the study of fat metabolism.

LORD ROTHSCHILD,

G.M., Sc.D., F.R.S.,

Was born in London in 1910, and was educated at Harrow and at Trinity College, Cambridge, of which he became a Fellow. During the war of 1939–45 he was a bomb disposal specialist in the British Intelligence Service. Is now Assistant Director of Research in the Department of Zoology, Cambridge, doing research on the physiology of eggs, spermatozoa, and fertilization. He has been chairman of the Agricultural Research Council since 1948.

L. ESSEN,

D.Sc., Ph.D., A.M.I.E.E.,

Was born in 1908 and was educated at High Pavement School and University College, Nottingham. He joined the National Physical Laboratory in 1929 and has been responsible for the standards of frequency there since 1931. The quartz ring oscillator which he developed is now used at many observatories and standardizing laboratories throughout the world. During the war he developed measurement techniques for microwave frequencies and has since applied these techniques to the determination of fundamental constants and in particular to the construction of an atomic standard of frequency and time interval.

SIR ROBERT ROBINSON,

O.M., M.A., D.Sc., LL.D., F.R.S.,

Was born in 1886 and was educated at Fulneck School, near Leeds, and the University of Manchester. Appointed professor of organic chemistry in the University of Sydney in 1912, he has since held several professorial chairs, and from 1930 to 1955 was Waynflete Professor of Chemistry in the University of Oxford. He is an Honorary Fellow of Magdalen College. He is now associated with the Shell Chemical Company Limited. His scientific work has been concerned with the structure and synthesis of such natural products as alkaloids and anthocyanins, and with the application of electronic theories to the mechanism of reaction. He has been president of The Royal Society and of The Chemical Society, and is a medallist of these and many other learned bodies. He was president of the British Association for the Advancement of Science in 1955. He is chairman of the Perkin Centenary Committee.

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Editor: TREVOR I. WILLIAMS, M.A., B.Sc., D.Phil., F.R.I.C.
Foreign Editor: J. A. WILCKEN, B.Sc., Ph.D.

Imperial Chemical Industries Limited, Millbank, London, S.W.1
Communications to the Editors should be addressed to North Block, Thames House, Millbank, London, S.W.1

The amateur in science

In these days science is so largely the province of those who make it a lifelong profession that there is a tendency to look upon the efforts of the amateur as undeserving of serious attention. In fact, however, the amateur—by which in the present context is meant one for whom the pursuit of science is a secondary activity in life—has not only made many outstanding contributions in the past but can still play a part even today.

Historical examples abound. Thus on 19th November 1764 the senate of the university of Cambridge unanimously elected to the chair of chemistry a man who, on his own confession, 'had never read a syllable on the subject, nor seen a single experiment'. This was Richard Watson (1737–1816), afterwards bishop of Llandaff. The action of the senate neither excited nor called for unfavourable comment. In those days the body of scientific knowledge was so limited that, given intelligence and application, a novice might in a year or two acquire sufficient mastery of chemistry or most other branches of science to make his appointment to a chair reasonable. In this particular instance the choice turned out well; Watson possessed ability of a high order, had been second wrangler, and before very long was discharging his professional duties with dignity and efficiency.

Even as late as the second half of the eighteenth century no long period of training was necessary to bring a man to the frontiers of science, and the ingenious and inquiring amateur might reasonably hope by his own efforts to advance those frontiers a measurable distance. There were, indeed, comparatively few openings for the professional scientist, and many, perhaps the majority, of the most striking scientific discoveries dating from before the nineteenth century had been made by men who, as far as science was concerned, were amateurs—though many of them were mathematicians, physicians, or apothecaries.

With the rapid growth of science and technology in the period following the industrial revolution, conditions gradually changed. There were now increasing demands for full-time scientists, and the knowledge required of them necessitated more study and practical experience than could be afforded by those whose principal activities lay in other fields. Concurrent with the accelerating expansion of knowledge was an increase in the material equipment necessary, or at least very desirable, for the successful prosecution of such sciences as chemistry and physics. In these regions diminishing opportunities led to a diminution in the amount and importance of amateur contributions, but other fertile provinces were still open. The tendency of the amateur was now to gravitate towards the less highly specialized and less technical sciences, particularly geology, botany, and zoology, and a great deal of very valuable work was here accomplished by non-professional enthusiasts during the nineteenth century.

Geology had an irresistible fascination for a civil engineer and estate steward named William Smith (1769–1839), who used the opportunities afforded him by his profession to make extensive investigations on stratigraphy. Here the brilliant work of an amateur needs no recounting: his methods of identifying strata by their fossil contents, and his geological maps of Britain, made him the 'father of British geology'. Smith was in fact the founder of stratigraphical geology.

On the other side of the English Channel similar fame was won by the Provençal elementary school master Jean Henri Fabre, who in a characteristically modest way devoted his exceptional powers of patience and acute observation to the study of insects, particularly the hymenoptera and coleoptera. The worth of his work, and the esteem in which it was held, are manifested by the fact that his *Souvenirs entomologiques* (1879–1907) had the honour of being crowned by the Institute of France. Other continental amateurs who left their mark upon science were Wilhelm Hofmeister the botanist (1824–77), who carried out his chief work while still an assistant in a music-shop, and, in a class by himself, Gregor Mendel, abbot of Brünn (1822–84), whose experiments on inheritance in the garden pea were of basic importance in the establishment of the modern science of genetics.

Although nineteenth-century amateur science was in the main biological and geological, contributions to chemistry and the physical sciences were not altogether lacking. The fundamental reaction in the contact process for making sulphuric acid was discovered by a vinegar-manufacturer, and the removal of phosphorus from Bessemer steel was successfully accomplished on lines thought out by a police-court clerk. The early science of photography owed very much to the efforts of Fox Talbot (1800–77), scion of a noble family, who was the first to show how an unlimited number of positive images could be made from a photographic negative, was a pioneer of instantaneous photography and photographic engraving, and in the leisure he allowed himself from his scientific pastimes became one of the first to decipher the cuneiform inscriptions of Nineveh.

The science of astronomy owes much to the amateur. William Herschel—who has been called the 'father of modern astronomy'—was by profession a musician, and he first began to make telescopes, an activity which later became his main source of income, because he could not afford to buy them. Schwabe, whose patient observation of the sun led to the discovery of the periodicity of sunspots, was an apothecary. Carrington was another amateur who made major discoveries in this field; he was the first to observe solar flares and to remark their association with disturbances in the earth's magnetic field. William Huggins, a pioneer in stellar spectroscopy and a President of the Royal Society, was a business man. In recent years the brothers McMath in Michigan, who were engineers by profession, designed and constructed equipment, of ingenious and novel design, for solar observation.

The question of the possible role of the amateur in modern science is worth considering, for in all civilized countries there are large numbers of intelligent laymen whose interest in science is not confined to reading about the work of professional scientists but urges them to enlarge the realm of knowledge by personal effort. What scope have they? At a first glance it would seem very little. As the years pass, every branch of science becomes more recondite in its problems and more specialized in its technique. There was a time when scientific procedure was at least broadly intelligible to any man of education, but at the present day even scientists may find the work of fellow-scientists of other persuasions as obscure as the Eleusinian mysteries. If initiates themselves find this difficulty, the amateur nervously peeping in from the outside may well feel discouragement and dismay.

Reflection will lead us to modify this sombre conclusion. In the first place, the observational, as distinct from the experimental, aspects of many branches of science are still within the amateur's range, and such observational work has not become of less importance. Thus there have always been amateur astronomers; upon them professionals have relied to a considerable extent for observations of variable stars, searching for and discovering comets, and discovering novae.

The more immediate phenomena of the skies, those that form the study of meteorologists, have provided another rewarding field for the amateur, although radar methods have lately become increasingly important; as a science meteorology is in its infancy and offers innumerable problems for solution. The greater the mass of authentic data it has at its disposal, the rosier will grow the prospect of solving them. Seismology is in similar case, while oceanography, even if only oceanography from the shore, is yet another fruitful field. And no one will deny that there remain many opportunities for valuable amateur field-work in geology, petrology, and petrography.

Archaeology has perhaps suffered too bitterly from well intentioned but ill endowed amateurs to evince any great eagerness in accepting their assistance, but the itch to dig shows itself in the large numbers of local archaeological societies with which Britain and other lands are liberally sprinkled. An ardent desire to serve science ought not to be rebuffed, and archaeologists are clearly acting very properly in attempting to train and discipline those anxious to be of help. Sufficiently competent part-time workers can be of great value to the science, particularly in view of the heavy cost of hired labour.

Ecology, of both plants and animals, is a further activity in which the amateur may find a satisfying and useful outlet for his energy. Ecological studies cannot be carried out in a hurry; they call for long-continued and methodical observation and make demands upon time that the professional botanist or zoologist may find it hard to meet. As in entomology, which never lacks its numerous lay disciples, accumulation of properly authenticated data by amateurs will prove of considerable worth to those engaged in the more technical study of the subject.

Many amateur scientists, however, will remain unsatisfied with mere observation. They wish to experiment, and are willing to make a modest outlay on equipment. There is much they could do with quite limited equipment. Thus an amateur need not be disheartened by sparseness of apparatus even if his taste is towards experiments in chemistry: it is said that Adolf von Baeyer rarely used any apparatus beyond the test-tube, and even if this is an exaggeration it remains true that great work has often been accomplished with very simple means.

Mesons, hyperons, and antiprotons

H. S. W. MASSEY

Recent research, which has resulted in the identification of a new range of fundamental particles, has shattered the belief that all matter is constructed from a relatively few simple units. While the nature and significance of these new particles are far from being completely understood, and there may well exist others, it has been possible to formulate some generalizations about the factors which determine the speed and nature of atomic transformations. While the fundamental validity of these generalizations is uncertain, they nevertheless provide a convenient working hypothesis for the further exploration of this exciting new field.

The establishment of the atomic constitution of matter gave rise to the hope that it would be possible to describe the properties of all matter in terms of a few fundamental units or particles. Just before the second world war it seemed, indeed, that we were very close to realizing this hope. The chemical properties and many of the physical properties of matter could be understood in terms of atomic structure based on the Rutherford nuclear model and the laws of quantum mechanics. Only five particles seemed to be involved: three structural units, the electron, proton, and neutron, and two cements, the photon or light quantum, and the meson. Protons and neutrons formed the tightly bound, positively charged atomic nucleus around which the negatively charged electrons revolved under the influence of the electrical attraction of the unlike charge. This attraction could be represented in terms of an exchange of light quanta between the charges. Similarly, exchange of mesons between nucleons (neutrons and/or protons) was supposed to provide the attraction holding the nucleus together. In 1935 H. Yukawa [1] had predicted that such mesons should have masses about 300 times that of the electron and be electrically charged. Particles with very similar properties were discovered in cosmic rays by C. D. Anderson and S. H. Neddermeyer [2] in 1937.

One phenomenon disturbing to this conception was that of beta-radioactivity, in which energy seemed to disappear and the conservation of angular momentum to be violated. It was suggested that actually energy and angular momentum are stolen away in a beta decay process by a particle called the neutrino, with so little interaction with matter as to be unobservable with present techniques.

Soon after fundamental research in this field began again after the war it was found that this apparently satisfactory and simple situation was an illusion. The meson which had been observed was found not to be the one required by Yukawa, although others apparently answering to his requirements were found in cosmic radiation at high altitudes. Apart from this supernumerary meson, called the μ-meson to distinguish it from the Yukawa type π-mesons, others, known as κ-mesons, have been found recently. These mesons, though over three times as heavy as the π-mesons, have masses only about two-thirds that of the proton. To add to the confusion, other particles, known as hyperons, have been observed which have masses between 25 and 40 per cent greater than that of a proton or neutron.

Of all this multitude, the only ones which are stable when free are the proton, the electron, the light quantum, and, seemingly, the neutrino. All the others decay in one way or another, often by a complicated sequence of processes, into one or more of these stable particles. The neutrino seems to play an important part in many of these decay processes. It is interesting to note that the development of technique has been so rapid that within quite a short time we should know whether it does exist or not.

Although we have at present no inkling of the part played by the unexpected particles in the scheme of things, we must point out, in fairness to the theoretical physicists, that the existence of two particles with remarkable properties (apart from Yukawa's meson) was predicted theoretically. These are the positron or positive electron, and the negative proton or antiproton. Both have since been observed—the positron nearly 24 years ago, the antiproton [3] during the past few months (see page 127).

The behaviour of particles moving with high energy is in many ways very different from that of ordinary matter at ordinary speeds. Both relativistic and quantum modifications must be introduced. We shall begin by summarizing the essential features of these modifications as they relate to the study of fundamental particles. After a brief account of the experimental techniques employed we shall conclude with a summary of the present situation.

MASS, MOMENTUM, AND ENERGY IN RELATIVITY THEORY

The motion of a particle can no longer be described accurately by classical mechanics when its velocity v is not small compared with that of light (c). Thus the classical expression mv of the momentum, m being the mass, is really only an approximation to the relativistic formula $mv(1 - v^2/c^2)^{-\frac{1}{2}}$. This is just as if the mass varied with the velocity. The constant m is usually referred to as the rest mass of the particle.

Remarkable consequences follow when the relativistic modifications of the concept of energy are considered. The total energy of the particle is found to be $mc^2(1 - v^2/c^2)^{-\frac{1}{2}}$. When v/c is small this is approximately $mc^2 + \frac{1}{2}mv^2$, i.e. the kinetic energy of classical mechanics plus a term mc^2, which has no classical analogue. This additional energy arises from the possession of rest mass, and it suggests that energy of this kind might be transformed into other forms such as kinetic energy, radiant energy, and so on; in other words, the annihilation of matter and its reappearance as some other form of energy. Inverse transformations would also be expected in which rest mass energy, and hence matter, is created from radiant or kinetic energy. Such transformations are now commonplace in high-energy physics. They can be described theoretically only by allowing fully for both quantum and relativistic modifications of classical physics—the theory of quantized wave-particle fields, which is discussed below.

The momentum p and the energy E of a particle of rest mass m are connected through the relation

$$p^2 = \frac{E^2}{c^2} - m^2c^2 \quad \dots\dots\dots\dots(1)$$

For a particle with no rest mass, such as the light quantum or neutrino, we have $p = E/c$.

CHARACTERISTIC PROPERTIES OF FUNDAMENTAL PARTICLES

A fundamental particle is characterized by its rest mass, charge, spin, parity, its interaction with nucleons, and its mean lifetime and modes of decay.

The spin and parity need some explanation, though we shall defer consideration of the latter until a later section. As to the spin, it is first to be noted that, according to quantum theory, angular momentum is quantized. If it arises from orbital motion round a centre of force it is given by $\hbar\sqrt{\{l(l + 1)\}}$, where l is zero or a positive integer and $2\pi\hbar$ is Planck's constant. It appears that particles may also possess internal angular momentum or spin which has a definite value for each particle, given again by $\hbar\sqrt{\{l(l + 1)\}}$ but with l allowed now to take half-integral as well as integral values. Particles such as electrons, nucleons, and μ-mesons for which the spin is half-integral have certain fundamentally different properties from those, such as π- and κ-mesons and photons, for which it is zero or integral. The former are referred to as fermions, the latter as bosons, after Fermi and Bose respectively.

WAVE-PARTICLE FIELDS IN QUANTUM THEORY

Although we have hitherto adopted the customary convention of referring to 'fundamental particles', this is far from being a correct description in terms of modern quantum theory. We should talk instead of 'fundamental wave-particle fields'. To illustrate what is meant by this we shall discuss briefly two representative cases: that of the light quantum and of the electron respectively. These are distinguished by the fact that, in the classical limit, for light only the wave aspect remains, whereas for the electron it is the particle aspect which persists.

According to classical mechanics it is possible, given the initial values of the co-ordinates describing the system as well as the initial rates of change of these co-ordinates, to predict their values at any subsequent time, provided the forces acting on the system are known. This is not possible in quantum mechanics. The value of a quantity such as the energy or momentum characterizing the state of the system is no longer capable of continuous variation, but must be one of a set of allowed values. Moreover, it is possible to determine only what is the probability that, at some time, the quantity concerned will have any one of these values. Quantum mechanics provides the technique for determining the allowed values for any particular quantity and for calculating the probability that any one of these values will be assumed at a time t. Changes occur in the state of the system due to transitions of the quantities characterizing the state, from one set of allowed values to another. An important task of quantum theory is, therefore, the calculation of the probabilities of observed transitions. Given the classical theory of the motions of a given dynamical system, the necessary generalization to the quantum formulation—the process of quantization—now offers no difficulty.

In the consideration of our first example, light, the quantization of Maxwell's electromagnetic field leads to the following allowed values for the field energy and momentum.

Field energy: $\Sigma_s(n_s + \frac{1}{2})h\nu_s$, ...(2)

the nature of n_s being described below.

Field momentum (in a particular direction):

$$\Sigma_s n_s h\nu_s/c \quad \ldots\ldots\ldots\ldots (3)$$

The allowed frequencies are such that, if the field occupies a volume V the number of allowed values between ν and $\nu + d\nu$ is

$$\frac{4\pi\nu^2 d\nu}{c^3}\, V \ldots\ldots\ldots\ldots (4)$$

A state of the field characterized by the number n_s can be regarded as one in which there are n_s particles present of energy $h\nu_s$ and momentum of magnitude $h\nu_s/c$. These are the light quanta already referred to. It will be noticed that, even if there are no quanta present, the field energy does not vanish. This has interesting consequences, but it would take us too far from the main theme to discuss this point further.

Emission and absorption of light may now be described as transitions between states of the field in which n_s changes. Thus emission of a quantum of frequency ν_s involves a change of n_s from 0 to + 1, absorption of a single quantum of the same frequency a change from + 1 to 0, and so on.

In considering the electron field we must start one stage further on than for light quanta. This is because we have no classical electron field theory to work from, the electron being, classically, a particle. The first step is to quantize the classical theory of the motion of a single electron—first quantization. This introduces a continuous variable, usually called the wave function ψ of the electron, which is such that $|\psi^2|\delta v$ is the probability of finding the electron in the small volume δv. The wave function at this stage plays for the electron a role similar to that which the electromagnetic field strengths or potentials do for light quanta. A second quantization procedure may now be applied to the ψ-field, and it is found that the allowed values of the energy, momentum, and electric charge of the field are given by:

$$\begin{aligned}
&\text{Total energy} &&= \Sigma_s N_s E_s - \Sigma_s \mathcal{N}_s E_s \;..(5)\\
&\text{Total momentum} &&= \Sigma_s N_s p_s + \Sigma \mathcal{N}_s p_s \;....(6)\\
&\text{Total charge} &&= -\,e\Sigma_s N_s - e\Sigma_s \mathcal{N}_s \;..(7)
\end{aligned}$$

where e is the magnitude of the charge on an electron and p_s, E_s are related by the relativistic formula (1). In contrast to the electromagnetic field, the numbers N_s and $\mathcal{N}_s$ are restricted to either 0 or 1. This restriction is a consequence of the fact that the spin quantum number for an electron is $\frac{1}{2}$, as against 1 for a light quantum.

When $\mathcal{N}_s = 0$ we have a state in which there are N_s electrons present of momentum p_s, energy E_s, and charge $-\,e$. The situation is much less clear when $N_s = 0$, $\mathcal{N}_s \neq 0$. This would seem to be a state in which there are $\mathcal{N}_s$ particles present of momentum p_s, charge $-\,e$, but energy $-\,E_s$. Such particles, possessing negative kinetic energy, would have a negative rest mass and most unfamiliar properties. Thus, when acted on by a force, they would be accelerated in the opposite sense to the force! No particles of this kind have in fact been observed. Account may be taken of this by defining the vacuum state of the electron field as one in which the occupation numbers for all states of the 'unnatural' particles have their maximum values of 1. Thus, for the vacuum:

$$\begin{aligned}
&\text{Total energy} &&= -\,\Sigma_s \mathcal{N}_s E_s \;\;.... \;(8)\\
&\text{Total momentum} &&= \Sigma_s \mathcal{N}_s p_s \;\;.... \;(9)\\
&\text{Total charge} &&= -\,e\Sigma_s \mathcal{N}_s \;\;....(10)\\
&&&\mathcal{N}_s = 1,\ \text{all } s.
\end{aligned}$$

The magnitude of any particular quantity which will be observable for an electron field is then the difference from the value for the vacuum. Thus, subtracting (8), (9), and (10) from (5), (6), and (7) respectively, we have:

Observable total energy

$$\begin{aligned}
&= \Sigma_s N_s E_s - \Sigma(\mathcal{N}_s - 1)E_s\\
&= \Sigma(N_s + N_s^{+})E_s,\\
&\qquad \text{where } N_s^{+} = 1 - \mathcal{N}_s
\end{aligned}$$

Observable total momentum

$$= \Sigma(N_s - N_s^{+})p_s,$$

Observable total charge

$$= -\,e\Sigma N_s + e\Sigma N_s^{+},$$

with $N_s = 0, 1;\ N_s^{+} = 0, 1.$

A state in which $N_s = 0$, $N_s^{+} = 1$ may now be regarded as one in which a particle of energy E_s, momentum p_s, and charge $+\,e$ is present. This particle is known as a positron or anti-electron. It can be regarded as an absence of a particle of charge $-\,e$, momentum $-\,p_s$, and energy $-\,E_s$.

Unless it is assumed that positrons can be created under certain circumstances, the difficulty of the 'unnatural' particles would remain. The discovery of positrons by Anderson [4] and by P. M. S. Blackett and G. P. S. Occhialini [5] was a striking confirmation of the quantum theory of the electron field.

THE PROTON FIELD AND THE ANTIPROTON

The proton has a half-integral spin quantum number just as an electron has, so the theory of the quantized proton field follows exactly similar lines. In particular, the theory requires the existence of an antiproton bearing to the proton the same relation as the positron does to the electron. Thus the antiproton should have the same mass as a proton, but possess a negative charge, $-e$, in place of the positive charge of the proton.

FIELDS IN GENERAL—PARITY

We may similarly associate a quantized field with every fundamental particle. All those particles which have half-integral spin will have fields of the electron and proton type, with the corresponding antiparticles. Such particles are called fermions and are to be distinguished from those called bosons, which have integral or zero spin and fields of the photon type.

The parity of a wave-particle field is determined by the way the field variable transforms when the reference axes are changed from a right-handed set to a left-handed set. It must either be unaltered or changed in sign. In the former case it is said to have parity $+1$, in the latter -1. The rate of a reaction such as

$$\mathrm{A} + \mathrm{B} \rightarrow \mathrm{C} + \mathrm{D}$$

must clearly be independent of the choice of reference axes, so that if p_{A}, p_{B}, p_{C}, p_{D} are the respective parities of the corresponding fields,

$$p_{\mathrm{A}} p_{\mathrm{B}} = p_{\mathrm{C}} p_{\mathrm{D}},$$

an example of the so-called conservation of parity.

INTERACTIONS BETWEEN FIELDS—CREATION AND ANNIHILATION PROCESSES

The various wave fields are not independent, but interact with each other. Because of this interaction, transitions may take place simultaneously between states of the two fields so that energy, momentum, angular momentum (including spin), charge, and parity are conserved. All collision or decay processes can be described in this way.

Thus consider the interaction between the electromagnetic and electron fields. A process in which an electron of initial energy E_i emits a quantum of frequency ν_j so that its energy is reduced to E_f involves a transition between states of the electron and photon field:

Initial state	*Final state*
$N_s = 0, s \neq i$	$N_s = 0, s \neq f$
$= 1, s = i$	$= 1, s = f$
$N_s^+ = 0$, all s	$N_s^+ = 0$, all s
$n_s = 0$, all s	$n_s = 0, s \neq j$
	$= 1, s = j$

That is to say, we have annihilation of an electron in state i and creation of an electron in state f and of a photon with frequency ν_j. Bearing in mind the conservation rules, we can see how a positron-electron pair may be materialized from a light quantum of frequency ν_k. Here we have

Initial state	*Final state*
$N_s = 0$, all s	$N_s = 0, s \neq l$
$N_s^+ = 0$, all s	$= 1, s = l$
$n_s = 0, s \neq k$	$N_s^+ = 0, s \neq n$
$n_k = 1$	$= 1, s = n$
	$n_s = 0$, all s

and $h\nu_k = E_l + E_n$.

Since E_l and E_n are each never less than mc^2, it follows that the threshold frequency for producing a pair is $2mc^2/h$. This applies to materialization of kinetic, as well as radiant, energy in the form of an electron-positron pair. For materialization of a proton-antiproton pair the available energy must exceed $2Mc^2$, where M is the proton mass. The inverse process of mutual annihilation of the pair will release energy not less than this.

It is because of the need to make available sufficient kinetic energy to create the rest masses of the unstable particles that this branch of physics necessarily involves high energies.

Apart from the five conservation rules mentioned at the outset, it seems likely that one other quantity is also conserved in all transformations and that a still further general restriction is imposed. These will be discussed explicitly in later sections (page 125).

As the study of fundamental particles is largely one of energy transformations, a clear and convenient choice of energy unit must be made. The choice is the electron-volt, which is the energy acquired by an electron when falling through a potential difference of one volt. It is equal to $1{\cdot}6 \times 10^{-12}$ ergs. 10^6 eV is usually denoted as 1 MeV and 10^9 eV as 1 GeV.

The rest mass of an electron is equivalent to $\frac{1}{2}$ MeV, that of a proton to 950 MeV, and those of the mesons to intermediate values. Obviously the first necessity for research in this field is the availability of a source of particles with kinetic energies of this order or greater.

SOURCES OF HIGH-ENERGY PARTICLES

Until 1947 the only available source of particles with sufficient energy to create mesons was the natural one of cosmic rays. Primary cosmic rays form π- and κ-meson secondaries in the atmosphere, mainly at a height of about ten miles above the surface. These decay to the less interesting μ-mesons quite rapidly, so that to obtain a good yield of the interesting particles it is necessary to send detecting apparatus up as high as possible; hence the establishment of cosmic ray stations on high mountains and the carriage of nuclear emulsion detectors to upwards of 80 000 ft. by balloons.

The rapid development of artificial means of accelerating particles to high energies reached such a stage that in 1947 the cyclotron at Berkeley was able to accelerate alpha-particles to an energy (400 MeV) great enough to produce π-mesons. The cosmotron at Brookhaven (2·2 GeV) and the bevatron at Berkeley (6·2 GeV) now accelerate particles to energies great enough to create κ-mesons. The bevatron has gone even further in producing antiprotons. Plans exist for yet more powerful machines, including one designed to reach 25 GeV at the European Nuclear Physics Laboratory at Geneva. For a recent survey of high-energy particle accelerators see [10]. Accelerators have the advantage over cosmic rays in providing more intense and more homogeneous beams. However, the most energetic cosmic ray particles are still well beyond the reach of artificial production, and must still be used for studies requiring very high energies.

TECHNIQUES FOR STUDYING FAST PARTICLES

All techniques for studying the properties of fast particles depend upon the fact that such particles ionize the atoms of matter through which they pass. Some of the electrons ejected from the atoms may themselves produce ionization. As a rough rule, about 30 eV of energy is expended for each electron-ion pair produced. A particle with 1000 MeV initial energy can therefore produce about 30 000 000 ion pairs along its path, representing a total separated charge of about $4{\cdot}8 \times 10^{-12}$ coulombs. Because of this high ionizing power the passage of individual particles may be registered and the actual track recorded photographically.

There are four main methods of utilizing the ionization. Three of these—the cloud chamber, the nuclear emulsion, and the bubble chamber—involve the actual photographic recording of tracks, while the fourth involves automatic counting of the number of particles with selected properties arriving at a selected location. These methods are complementary, and all have already yielded valuable results except the bubble chamber, which is a very recent invention and has not yet been in operation long enough to have made a big contribution.

The mode of operation of a Wilson cloud chamber is too well known to need much description here. It depends on the fact that condensation of vapour in a supersaturated gas can occur only when condensation nuclei are present. Ions and electrons, because of their charge, act as suitable nuclei. If a gas containing a vapour is expanded so as to produce supersaturation when an ionizing particle is passing through, condensation will take place along the track of the particle where it has produced ions and electrons. By suitable synchronization, the condensed droplets along the track may be photographed, thereby outlining the path of the fast particles. Figure 1 illustrates examples of tracks obtained in this way.

A nuclear emulsion is simply a photographic emulsion suitably sensitized so that a fast particle passing through it produces silver granules at points along its ionizing path. By a suitable developing and fixing process the track is photographed and may be viewed through a suitable microscope; figure 2 illustrates a micrograph of tracks obtained by this method.

A bubble chamber can be regarded in many ways as the inverse of a cloud chamber. It depends on the fact that a liquid heated, while under compression, to a temperature well above its boiling point at atmospheric pressure will not boil immediately the pressure is reduced to atmospheric unless suitable nuclei are present on which the bubbles can form. Charged particles are able to act as such nuclei, so that if a fast particle passes through the superheated liquid, boiling will begin along the track. Synchronized photography of the bubbles may then be used to observe the track of the fast particle. Figure 3 shows examples.

IDENTIFICATION OF PARTICLES FROM CLOUD CHAMBER, BUBBLE CHAMBER, AND EMULSION TRACKS

The mass of a particle may be determined, if its momentum and energy are known, from the relativistic relation (1). In principle, the momentum

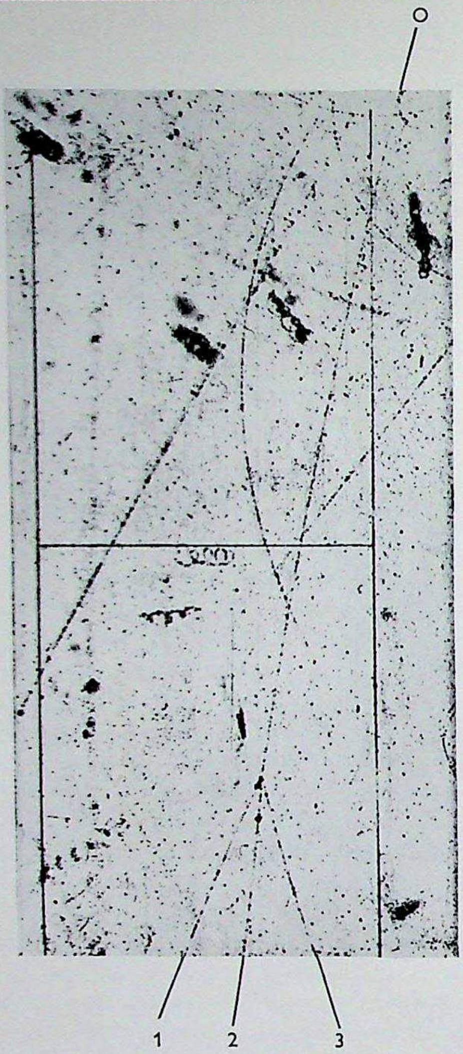

FIGURE 1 – *Cloud chamber photograph of the decay of a* τ*-meson into three* π*-mesons. The track of the* τ*-meson is indicated as* 0 *and those of the three* π*-mesons as* 1, 2, 3 *respectively. The photograph was taken with a magnetic field of several thousand gauss applied to the chamber, so that the track of the* τ*-meson is perceptibly curved. Also visible in the photograph are tracks of greater curvature due to particles of lower momentum.* (*The photograph is reproduced by kind permission of the Editors of the* Physical Review, *and of the authors, from a paper by Burwell, Huggett and Thompson* [8].)

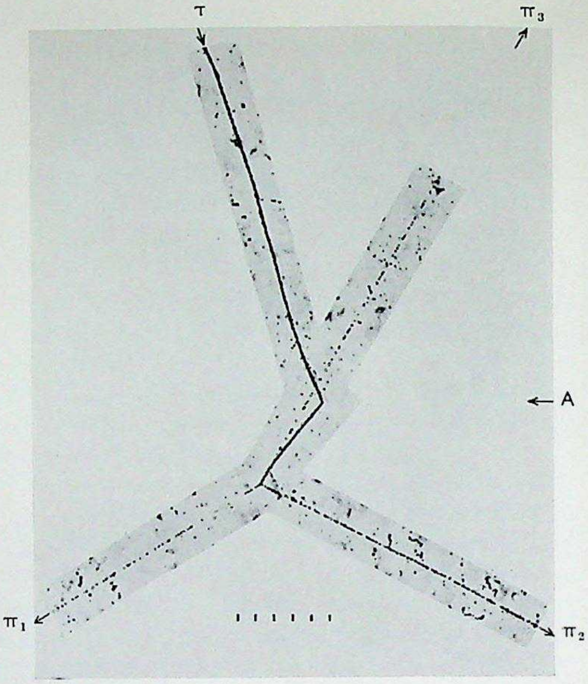

FIGURE 2 – *Micrograph showing the decay of a* τ*-meson in a photographic emulsion. The* τ*-meson track is very dense, as the meson is near the end of its range. It suffers a sharp deviation at A, due to a collision with a nucleus in the emulsion. The tracks of the three* π*-mesons are indicated as* π_1, π_2, *and* π_3 *respectively. In track* 1 *the grain density is increasing perceptibly as the* π*-meson slows down.* (*The photograph is reproduced by kind permission of the Editors of the* Philosophical Magazine, *and of the author, from a paper by Hodgson* [9]).

may be determined from the curvature produced in the track of the particle by application of a strong magnetic field. This is practicable in a cloud chamber because the density of the medium through which the fast particle is passing is so low that the path is not curved appreciably by the many small deflections due to collisions with the nuclei of the medium. Fields of the order of 10 000 gauss are often employed, and these enable momenta as high as 10 GeV/*c* to be measured with reasonable accuracy. In emulsions and bubble chambers the density of the medium is too high for magnetic methods to be useful, but here the momentum may be estimated from the curvature produced by the multiple small-angle scattering.

The energy may be calculated if the range of the particle in the chamber can be measured: the range is the total length of the track before the particle is brought to rest. For particles with energies greater than the rest-energies of the more massive particles the ranges are often so long that special arrangements must be made to measure them. One very fertile device is to use two chambers, as in figure 5. The upper one is designed to measure momentum by the magnetic method, but has little effect on the energy of the particle. It passes down into the lower chamber, in which there are parallel plates of strongly absorbing material such as lead. Between these plates the track can be observed and the plate in which it stops can be identified. From this the range in lead may be obtained, and hence the energy.

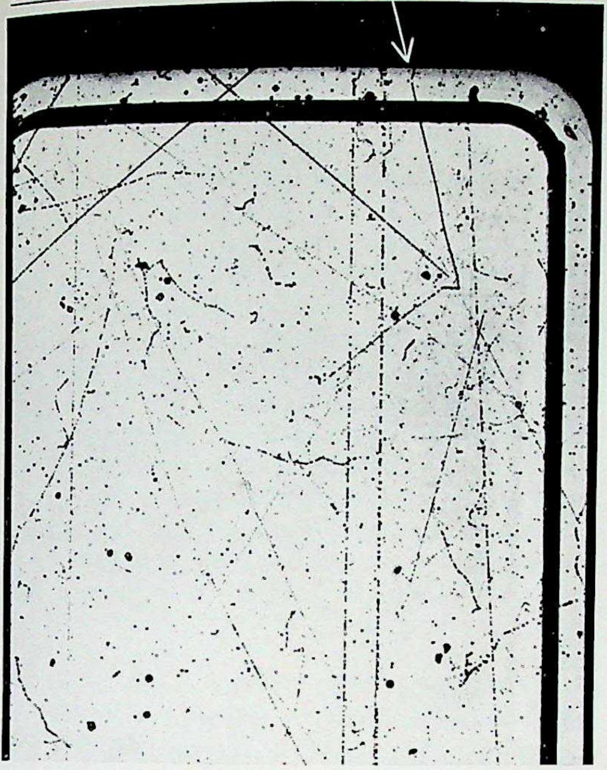

FIGURE 3 – *Photograph of tracks of fast particles in a propane bubble chamber exposed to the issuing beam from the cosmotron. The straight tracks are due to protons or* π-*mesons. The arrow indicates the track of a slow* π^+-*meson which at the end of its range decays into a* μ^+-*meson, which in turn decays to a positive electron, which gives the ultimate, much less dense, track.* (*This photograph was kindly supplied by Dr C. Dodd.*)

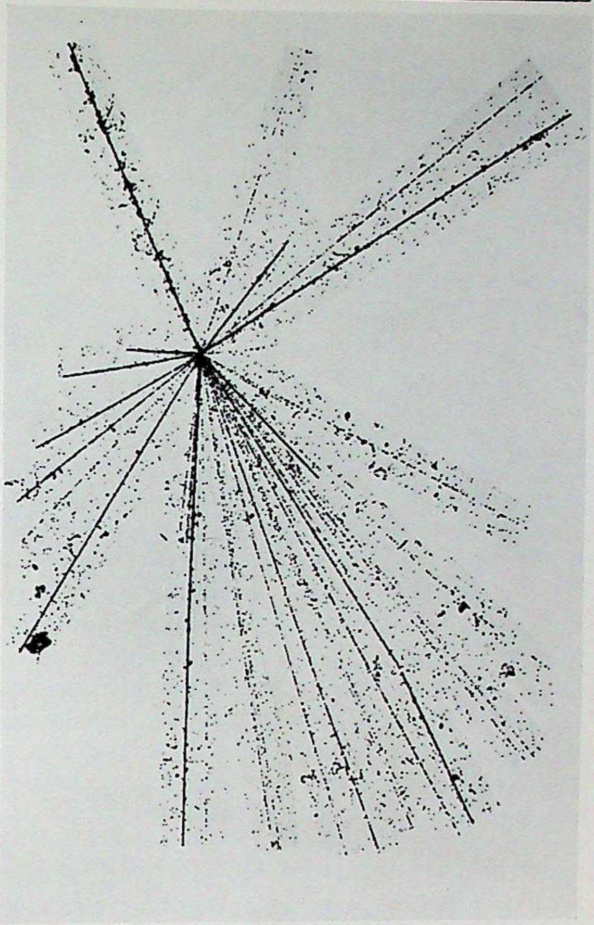

FIGURE 4 – *Micrograph showing a nuclear disintegration star produced by a* π-*meson. This is a characteristic event for a* π^--*meson. A* μ^--*meson does not produce a large star, while a* π^+-*meson decays into a* μ^+ (*see figure* 3) *and a* μ^+ *into an electron.* (*This photograph was kindly supplied by Dr P. Prowse.*)

In an emulsion the energy may be obtained from measurement of the density of developed grains along the track or from the so-called gap density, the number of gaps between grains per unit length of track. Calibration may be carried out by observations of tracks of particles of known mass and energy. The sense in which the grain density is increasing gives in any case the sense in which the particle is moving (see figure 2).

The nature of a particle forming an emulsion track may often be identified by noting what appears at the end of the track. Some decay process may have occurred (see figure 3) or the particle may have been absorbed by a nucleus of the emulsion, giving rise to a nuclear explosion or star as in figure 4. With experience, much may be deduced from these. For this reason it is an advantage to use an emulsion thick enough to bring to rest a particle produced in it. In addition, measurement of the range in the emulsion is a powerful means of determining the particle energy.

In recent years emulsion stacks made of a pile of emulsions stripped from their glass backings have been used with much success. They have been flown in balloons to altitudes near 100 000 ft so as to expose them to cosmic rays. Analysis of the processed stack is a long job, and it has been organized on a basis of international collaboration.

One recent stack, known as the G-stack, consisted of 250 sheets of emulsion 600 μ thick and with superficial dimensions 37 × 27 cm, weighing 300 lb. It was launched from Novi Ligure in Italy, and after a somewhat tortuous flight reached ground over the Apennines at a greater speed than anticipated, due to parachute failure. About one-tenth of the stack was destroyed, but the remainder has yielded useful results. The analysis was shared between the Universities of Bristol, Copenhagen, and Genoa, University College, Dublin, and the Institute of Advanced Studies, Dublin.

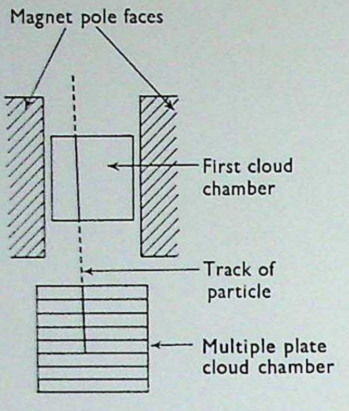

FIGURE 5 – *The principle of the double cloud chamber method for determining the mass and sign of the charge of fast particles. The fast particle track is shown in full line where it is observed in the cloud chamber, and as a dotted line elsewhere.*

Emulsion stacks are also of much value when used in conjunction with accelerators. By magnetic analysis it is possible to isolate from the machine a beam of particles with given momentum and allow it to irradiate a stack. Particles in this beam with a definite mass will have a definite range in the stack, and so may be separated.

COUNTER METHODS

A counter is a device which records the passage of an ionizing particle through it. The best known type is the Geiger counter, but for many purposes this is being replaced by the scintillation counter, which is a modern version of the original scintillation method used by Rutherford for counting alpha-particles from radioactive substances. Fast particles impinging on suitable substances, known as phosphors, produce flashes of light. These were observed visually in Rutherford's experiments, often with much difficulty and uncertainty. In the modern technique the light flashes are piped to a photomultiplier, which transforms them into electrical impulses which are automatically recorded. The sensitivity is then enormously greater and subjective influences are absent. It is also possible to obtain information about the nature and energy of the particle from the character of the electrical impulse produced.

Another type of counter depending on light emission is the Čerenkov counter. A fast particle passing through a medium with a speed greater than the velocity of light in the medium produces electromagnetic shock waves, analogous to the shock waves generated by an aeroplane flying at a Mach number greater than 1. These waves appear as light, which may be observed by photomultiplier methods. Counters of this kind are selective as far as particle speed is concerned, and this selectivity may be increased by limiting the cone of emission of the observed light.

Counter methods are capable of high accuracy and discrimination. It is possible to make use of the great flexibility of modern electronic circuits to combine sets of counters so that the only impulses recorded are those which operate certain counters and not others. Alternatively, in addition, it may be arranged that the desired impulses are those which operate one set at a certain instant and another set after a suitable time delay, which may be as small as one microsecond or even less. Such arrangements make it possible to count selectively particles of one kind and one energy from a mixed beam. A recent illustration of these techniques in operation is the discovery of the antiproton, described later.

THE OBSERVED PARTICLES

These may be classified as fermions and bosons respectively (p. 118). The fermions (table I) include the electron, positron, and neutrino, the μ-mesons, the nucleons and antinucleons, and the hyperons (table III); the bosons (table II) are made up of the photon, the π-mesons, and the κ-mesons. The last column of table I will be referred to later.

The question marks indicate possibilities as yet unconfirmed or data not yet obtained. The most remarkable recent development is the evidence that all the κ-mesons have the same mass. They cannot, however, represent only three particles (with positive, zero, and negative charges respectively) with various alternative modes of decay. The τ-mesons must have different parity from the θ^0, $\kappa^+_{\pi 2}$, and $\kappa^-_{\pi 2}$ varieties. It is possible, however, that the κ-mesons may represent only two sets of three particles with different modes of decay; they have been provisionally called tauons and thetons respectively. Figures 1 and 2 show the decay of a τ-meson as observed in an emulsion and in a cloud chamber respectively.

DISCUSSION OF THE OBSERVED DATA

It appears possible to represent all the forces occurring in Nature (apart from the force of gravity) in terms of contact interactions between certain particles. Apparent action at a distance can be regarded as arising from exchange between the interacting systems of intermediary particles with which each has contact interaction. The strongest contact interactions are those of π- and κ-mesons with nucleons and hyperons. In some way, the details of which are not yet clear, they give rise to the forces which bind nucleons so firmly in nuclei. Next in strength are those between photons and charged particles, leading in particular to the Coulomb forces between charges. Finally, we have the weak interactions which lead to processes involving neutrino production or absorption.

The π-mesons are produced by the acceleration of sufficiently energetic nucleons in much the same way as photons are by the acceleration of charged particles (i.e. X-ray production by accelerating electrons). It does not seem, however, that the κ-mesons are produced quite so simply, but first we must note certain general considerations involving the hyperons.

HYPERON PRODUCTION— THE CONSERVATION OF BARYONS

No examples have yet been found of hyperon production in which the whole mass has been created from kinetic energy. It appears that a hyperon must be built on a nucleus as basis. In the same way no reaction has been observed in which the whole mass of a hyperon has been transformed into kinetic energy or rest-mass energy of particles lighter than nucleons. This suggests that hyperons together with nucleons constitute a conserved class of particles which are referred to as baryons. We then have the new conservation rule: 'In any reaction the number of baryons must be conserved.'

ASSOCIATED PRODUCTION— THE 'STRANGENESS' QUANTUM NUMBER

It follows from the baryon conservation rule that a hyperon can be produced only in a collision between two particles if one at least is a nucleon. A further remarkable fact is that in all observed cases a hyperon is produced only in association with one or more κ-mesons. Thus we have the reactions

$$\left.\begin{array}{ll} & \pi^- + P \rightarrow \Lambda^0 + \theta^0 \\ \text{or} & P + P \rightarrow P + \kappa^+_\mu + \Lambda^0 \end{array}\right\} \quad \ldots.(11)$$

$$\left.\begin{array}{ll} \text{but never} & \pi^- + P \rightarrow \Lambda^0 + \pi^0 \\ \text{nor} & N + P \rightarrow \Lambda^0 + P \end{array}\right\} \quad \ldots.(12)$$

Furthermore, it seems that, while a κ+- or κ−-meson can be produced singly in association with a hyperon, a κ−-meson can be produced only in association with at least one other κ-meson in addition.

It has been shown by M. Gell-Mann [6], following earlier work of A. Pais [7], that the available data can be ordered in terms of a selection rule. To each meson, nucleon, and hyperon is allocated a number which, as an indication of the ignorance it conceals, is known as the 'strangeness' quantum number. These assignments are listed in the last columns of tables I, II, and III. A reaction can be a fast one only if the algebraic sum of the strangeness quantum numbers on each side of the reaction equation is the same. By a fast reaction is meant one which takes place in a time of the order of 10^{-23} sec. If the total strangeness changes by ± 1 the time will be very much longer—of the order of the lifetimes of the κ-mesons and hyperons (see tables II and III). The probability of the reaction is negligible if the total strangeness changes by more than 1.

This scheme fits all the known data. Thus, referring to reactions (11) and tables II and III we see that in each case the total strangeness is unchanged and they lead to relatively copious production. On the other hand, in reactions (12) there is a change of total strangeness and the reactions are negligible sources of hyperons. Again, with the assignment − 1 as the strangeness of κ^-, the reaction $P + N \rightarrow P + \kappa^- + \Sigma^+$ involves a change of strangeness. To avoid this we must turn to reactions such as

$$P + P \rightarrow P + P + \kappa^- + \kappa^+$$

which require much more conversion of kinetic energy into energy of rest-mass.

The decay processes listed in tables II and III, which do not involve production of neutrinos, all involve a change of ± 1 in total strangeness. It is because of this that they are so slow.

So far the physical significance of the strangeness quantum number remains obscure. It is encouraging, however, that such a wide variety of data on the production and decay processes of κ-mesons and hyperons can be ordered in this simple way. The rules also seem to determine correctly the nature of the reactions of κ-mesons with nucleons.

HYPERNUCLEI

An interesting discovery is that hyperons may replace nucleons in nuclei to produce so-called hypernuclei which decay, in times of the order of the hyperon lifetimes, to produce normal nuclei and π−-mesons. Examples are hyperhelium nuclei, which include 2 protons, 1 neutron, and 1 Λ^0 hyperon. A specially interesting one is hyper H^4, consisting of 1 proton, 2 neutrons, and a Λ^0

TABLE I

The fermions (apart from the hyperons, for which see table III) all have spin ½

Particle	Symbol	Charge (in units e)	Mass / (electron mass)	Decay products	Lifetime (seconds)	'Strangeness' quantum number
Neutrino	ν	0	0	Stable	—	—
Electron	e^-	− 1	1	Stable	—	—
Positron .. .. (anti-electron)	e^+	+ 1	1	Stable	—	—
μ-meson	μ^-	− 1	207	$e^- + 2\nu$	$2 \cdot 2 \times 10^{-6}$	—
	μ^+	+ 1	207	$e^+ + 2\nu$	$2 \cdot 2 \times 10^{-6}$	—
Proton	P	+ 1	1836·6	Stable	—	0
Antiproton ..	P^-	− 1	1836·6	Stable	—	0
Neutron	N	0	1839·0	$P + e^- + \nu$	770	0
Antineutron ..	N^*	0	1839·0	$P^- + e^+ + \nu$ (Not yet observed)	?	0

TABLE II

The bosons all have spin 0 except the photon, which has spin 1

Particle	Symbol	Charge (in units e)	Mass / (electron mass)	Decay products	Lifetime (seconds)	'Strangeness' quantum number
Photon	γ	0	0	Stable	—	—
π-mesons	π^+	1	273	$\mu^+ + \nu$	$2 \cdot 5 \times 10^{-8}$	0
	π^0	0	265	2ν or $2e^+ + 2e^-$	$\sim 5 \times 10^{-15}$	0
	π^-	− 1	273	$\mu^- + \nu$	$2 \cdot 5 \times 10^{-8}$	0
κ-mesons: Tauons (?) ..	τ^+	1	966	$2\pi^+ + \pi^-$ or $\pi^+ + 2\pi^0$	10^{-8}	1
	τ^-	− 1	966	$2\pi^- + \pi^+$	?	− 1
	$\kappa^+_{\mu 2}$	1	966	$\mu^+ + \nu$	10^{-8}	1
Thetons (?) ..	θ^0	0	966	$\pi^+ + \pi^-$	$1 \cdot 7 \times 10^{-10}$	± 1
	$\kappa^+_{\pi 2}(\theta^+ ?)$	1	966	$\pi^+ + \pi^0$	$3 \cdot 7 – 8 \cdot 5 \times 10^{-10}$	1
	$\kappa^-_{\pi 2}(\theta^- ?)$	− 1	966	$\pi^- + \pi^0$	?	− 1
	$\kappa^+_{\mu 3}$	1	966	$\mu^+ + 2\nu$ (?)	?	1
	$\kappa^+{}_{e3}$	1	966	$e^+ + 2\nu$ (?)	?	1

TABLE III

The hyperons (fermions with mass greater than that of the proton)

Particle	Charge (in units e)	$\frac{\text{Mass}}{\text{(electron mass)}}$	Decay products	Lifetime (seconds)	'Strangeness' quantum number
Λ^0	0	2181	$P + \pi^-$	$3{\cdot}7 \times 10^{-10}$	-1
Σ^+	1	2327	$N + \pi^+$ $P + \pi^0$	$0{\cdot}3 \times 10^{-10}$	-1
Σ^-	-1	?	$N + \pi^-$	$0{\cdot}3 \times 10^{-10}$	-1
Σ^0	0	?	$\Lambda^0 + \gamma$	?	-1
Ξ^-	-1	2577	?	?	-2

hyperon. 'Normal' H^4 is not stable, because the third neutron cannot occupy as low a level as the first two, an exclusion which does not apply if the neutron is replaced by a hyperon.

DISCOVERY OF THE ANTIPROTON

The existence of the antiproton was demonstrated a few months ago [3] by the following technique. The particles issuing from a copper target bombarded by the 6·2 GeV beam of protons in the Berkeley bevatron were analysed by a magnetic field so that the issuing beam had a definite momentum and was negatively charged. This beam consisted mainly of π^--mesons moving with a velocity of 0·99 times that of light. Any antiprotons present would have the considerably lower velocity $0{\cdot}78c$.

Two scintillation counters were placed in the beam at 40 ft apart. π^--mesons traversed this distance in 4×10^{-8} sec. By noting the time delay between coincidences on the two counters it is possible in principle to tell whether the activating particle is an antiproton or not. As there were at least 40 000 times as many π^--mesons as antiprotons in the beam, it was necessary to eliminate chance coincidences very thoroughly. This was done by inserting two Čerenkov counters in the beam; one, A, was operated only by particles with velocity $0{\cdot}79c$, and the other, B, was operated only by particles with velocity between $0{\cdot}75c$ and $0{\cdot}79c$. In order that an antiproton should be recorded, the time delay on the original two counters had to be correct, and also Čerenkov counter B, but not A, operated as well. In the first experiment 250 of these events were recorded, very many more than could possibly be due to chance.

FUTURE PROSPECTS

The rapid development of technique, both in the scope of artificial acceleration and in methods of detection, is bound to provide much more extensive and precise data about the mesons, hyperons, and antiprotons. It may well be that most varieties of particle have already been discovered, but there may well exist others, whose lifetimes are so short as to defy detection by present methods. This applies particularly to neutral particles. It is not too optimistic to hope that, before long, some theoretical clarification of the relations between the particles will be made.

REFERENCES

[1] Yukawa, H. *Proc. phys.-math. Soc. Japan*, **17**, 48, 1935.

[2] Anderson, C. D. and Neddermeyer, S. H. *Phys. Rev.*, **51**, 884, 1937.

[3] Chamberlain, D., Segrè, E., Wiegand, C., and Ypsilantis, T. *Phys. Rev.*, **100**, 947, 1955. *Idem. Nature, Lond.*, **177**, 11, 1956.

[4] Anderson, C. D. *Science*, **76**, 238, 1932. *Idem. Phys. Rev.*, **43**, 491, 1933.

[5] Blackett, P. M. S. and Occhialini, G. P. S. *Proc. roy. Soc. A.*, **139**, 699, 1933.

[6] Gell-Mann, M. *Phys. Rev.*, **92**, 8332, 1953.

[7] Pais, A. *Ibid.*, **86**, 663, 1952.

[8] Burwell, J. R., Huggett, R. W., and Thompson, R. W. *Ibid.* (in press).

[9] Hodgson, P. E. *Phil. Mag.*, **42**, 1060, 1951.

[10] Cockcroft, J. D. and Pickavance, T. G. *Endeavour*, **14**, 61, 1955.

The Royal Society portraits

E. N. DA C. ANDRADE

The Royal Society has, in its long history, formed a considerable collection of portraits which is of general interest for both the eminence of many of the men they represent and the merit of many of the paintings. Owing to the way in which it has accrued, a number of characters not notable for great achievements in science, but nevertheless of interest, are included with figures of outstanding genius. The collection is here reviewed, the attribution of the well known portrait of Christopher Wren being among the questions considered.

The Royal Society from its early days has received gifts of portraits and today possesses a collection which is distinguished both by the outstanding genius of many of those depicted and by the mastery of many of the artists concerned. It is not always that the two are combined. The beautiful example of Hogarth's art in the Society's possession is a portrait of Martin Folkes, the antiquary, who was President from 1741 to 1752, but was a man of no great scientific distinction: in fact Stukeley records that under his presidency the meetings were 'a most elegant and agreeable entertainment for a contemplative person', which suggests no great scientific rigour. On the other hand, there are cases of men of great scientific eminence depicted by artists not conspicuous for their mastery, of which it would be ungracious to give examples.

On the whole, however, the standard of portraiture is high, and, among the older artists, men of the calibre of Lely, Kneller, Michael Dahl, Mary Beale, Reynolds, Thomas Lawrence, and Thomas Phillips are well represented. From 1880 to 1907 the Hon. John Collier, whose sober if uninspired veracity was well suited to academic portraiture and to the taste of the time, was supreme, having contributed seven portraits, including one of Charles Darwin (in copy) and a really excellent one of William Kingdom Clifford, a genius who, elected F.R.S. at the age of 28, died at 33.

Prominent among the early artists are Godfrey Kneller and Peter Lely, the leading English portraitists of their time—if we may call them English, for Kneller (originally Kniller) was born at Lübeck of good German stock and Lely was a Dutchman who came to England during the Civil War. To Lely is officially attributed the portrait of Viscount Brouncker, the first President of the Society as incorporated by the Charter of 1662. Brouncker was a considerable mathematician, whose work on continued fractions is recorded in the standard histories of mathematics. He continued as President until 1677, when he was succeeded by Sir Joseph Williamson, a statesman and diplomat who knew little of science, but took an interest in the affairs of the Society. Evelyn records of him that on 4th December, 'Being the first day of his taking the chaire, he gave us a magnificent supper'. He presented a fine portrait of himself, by Kneller, to the Society.

To Lely is somewhat doubtfully attributed the portrait of Charles II, Founder of the Society, which hangs over the President's chair. Contrary to the usual belief, the portrait did not come into the Society's possession at, or near, the time of the foundation. It belonged to the Marquis of Hastings, who died in 1826, and was acquired after his death. Another portrait attributed to Lely is that of Henry More, the Cambridge Platonist, elected Fellow in 1664 but never active in the scientific field. He was, however, a friend of many prominent Fellows, including Boyle and Newton.

Kneller is nominally responsible for more of the Society's portraits than any other single man. The best known of those that bear his name on the official list is that of Christopher Wren, who succeeded Joseph Williamson as President in 1680. Unfortunately it would seem that the portrait is not by Kneller at all, although in Elmes's 'Memoirs of the Life and Works of Sir Christopher Wren' (1823) it appears as the frontispiece, engraved 'after the Original Picture of Sir Godfrey Kneller's in the Council Chamber of the Royal Society'. In the 'Dictionary of National Biography' it is 'believed to be by Sir Peter Lely, though there seems some ground for attributing it to Sir Godfrey Kneller'. In the Royal Society printed catalogue of portraits dated 1860, compiled by C. R. Weld, who wrote a well known 'History of the Royal Society,' it is definitely set down to Lely, and as presented by Stephen Wren. Stephen Wren published in 1750, under the title

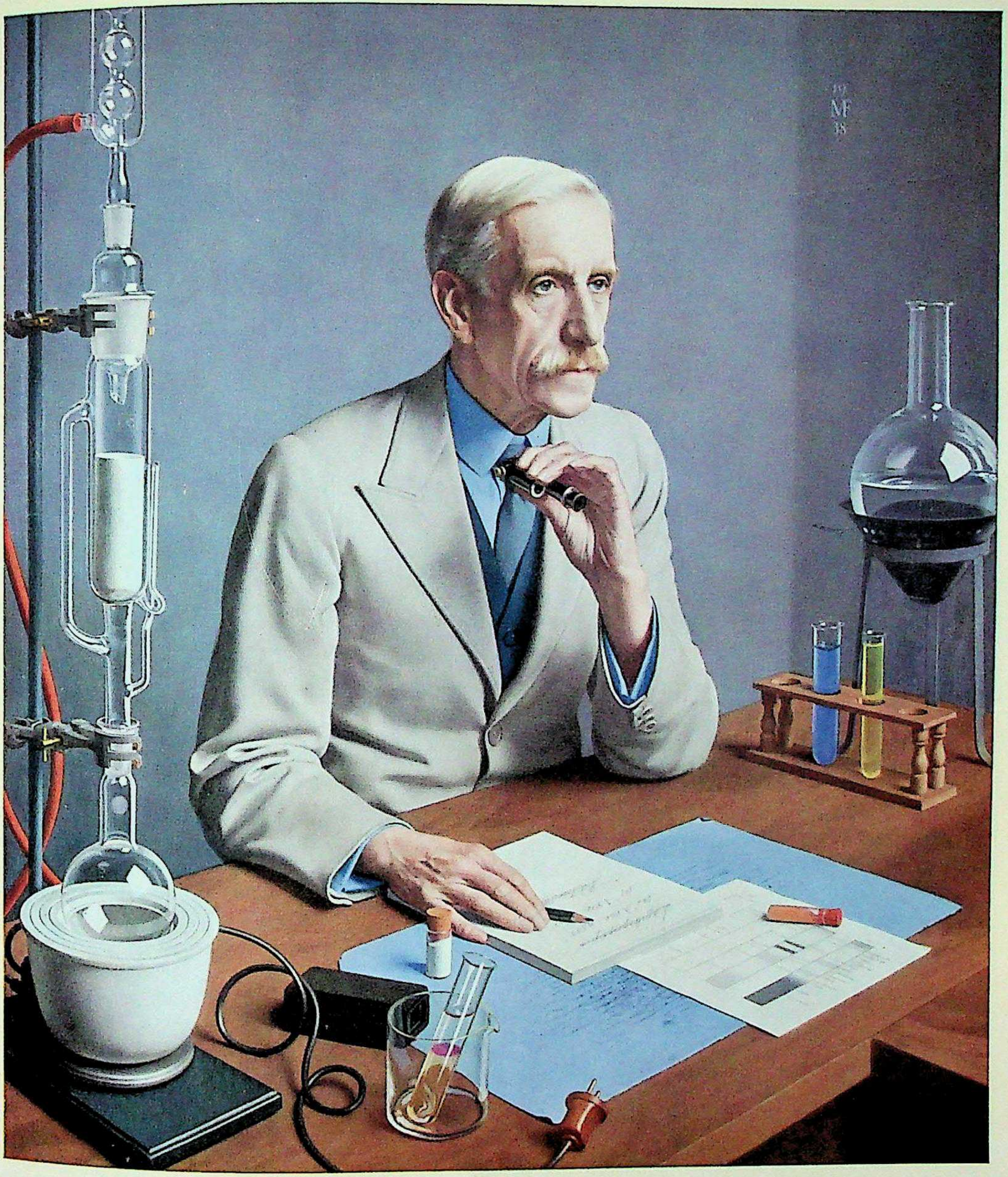

PLATE I – *Sir Frederick Gowland Hopkins, President* 1930–35. *By Meredith Frampton.*

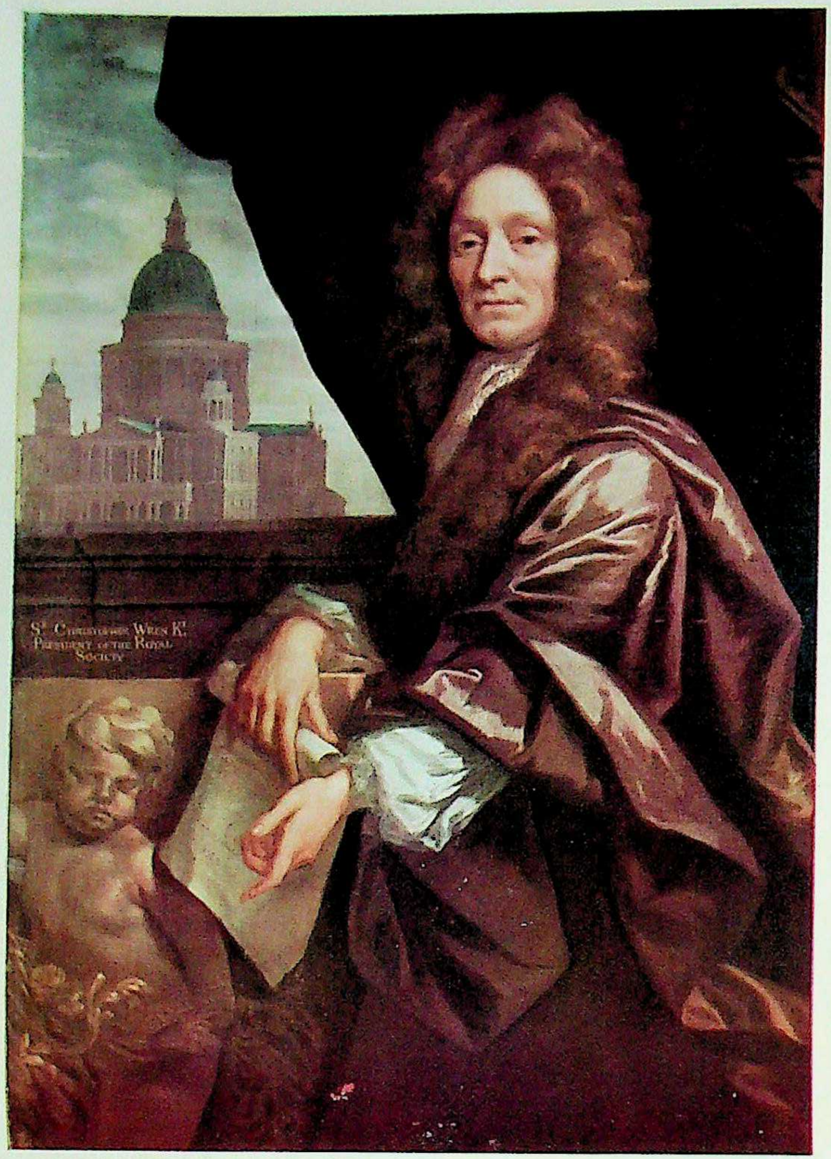
Sr. Christopher Wren Kt.
President of the Royal
Society

PLATE 2 – *Sir Christopher Wren, President* 1680–82. *Probably by J. B. Closterman.*

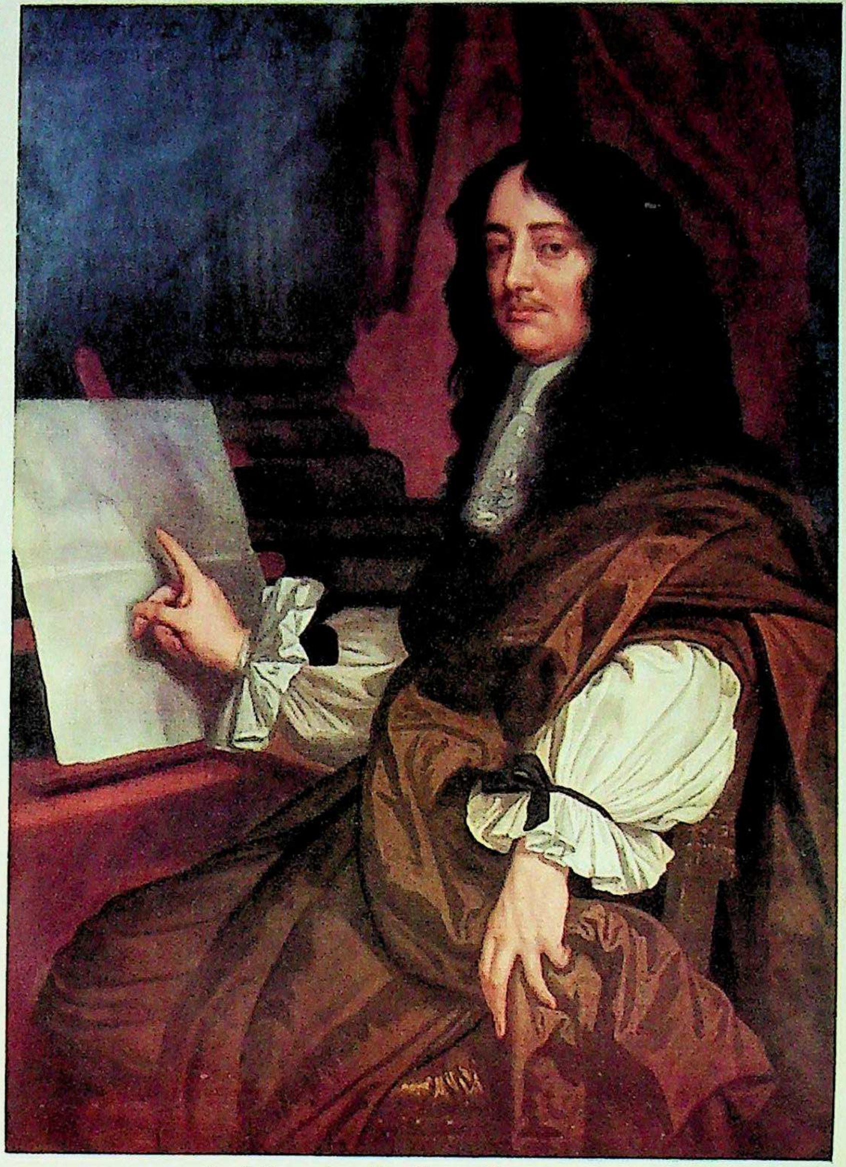

PLATE 3 – *Lord Brouncker, President* 1662–77. *By Sir Peter Lely.*

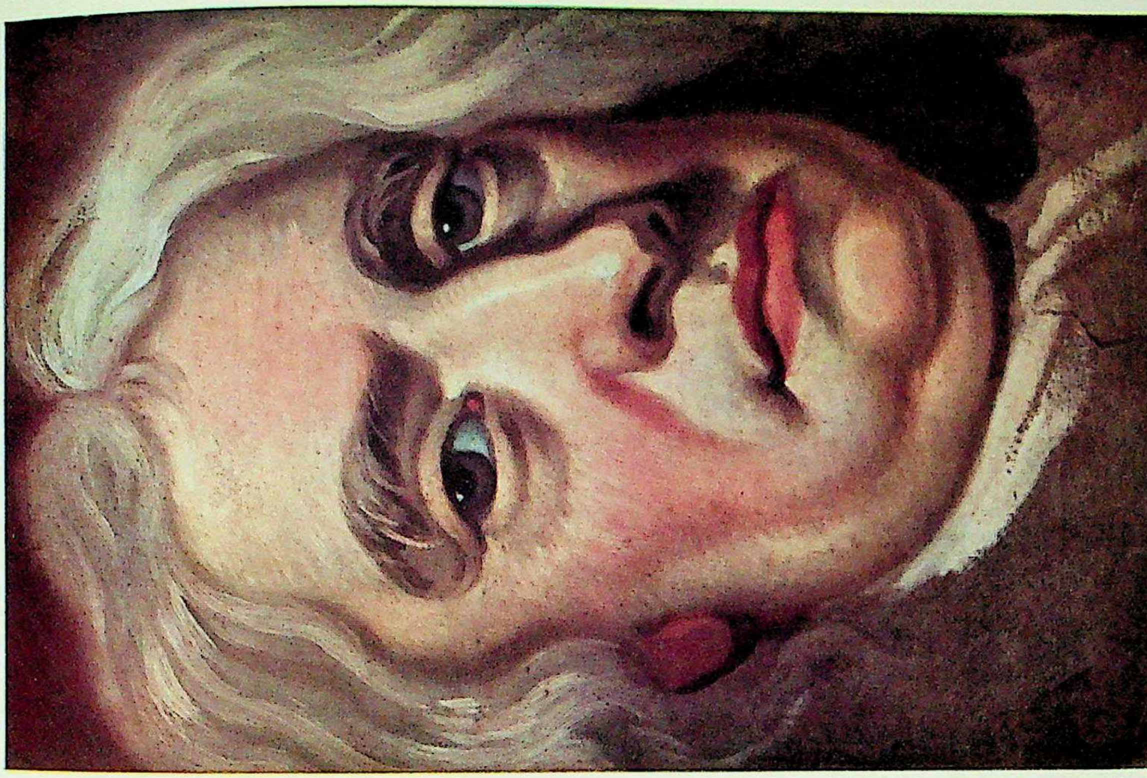

PLATE 5 – *Sir Isaac Newton, President 1703–27. Study by J. Vanderbank.*

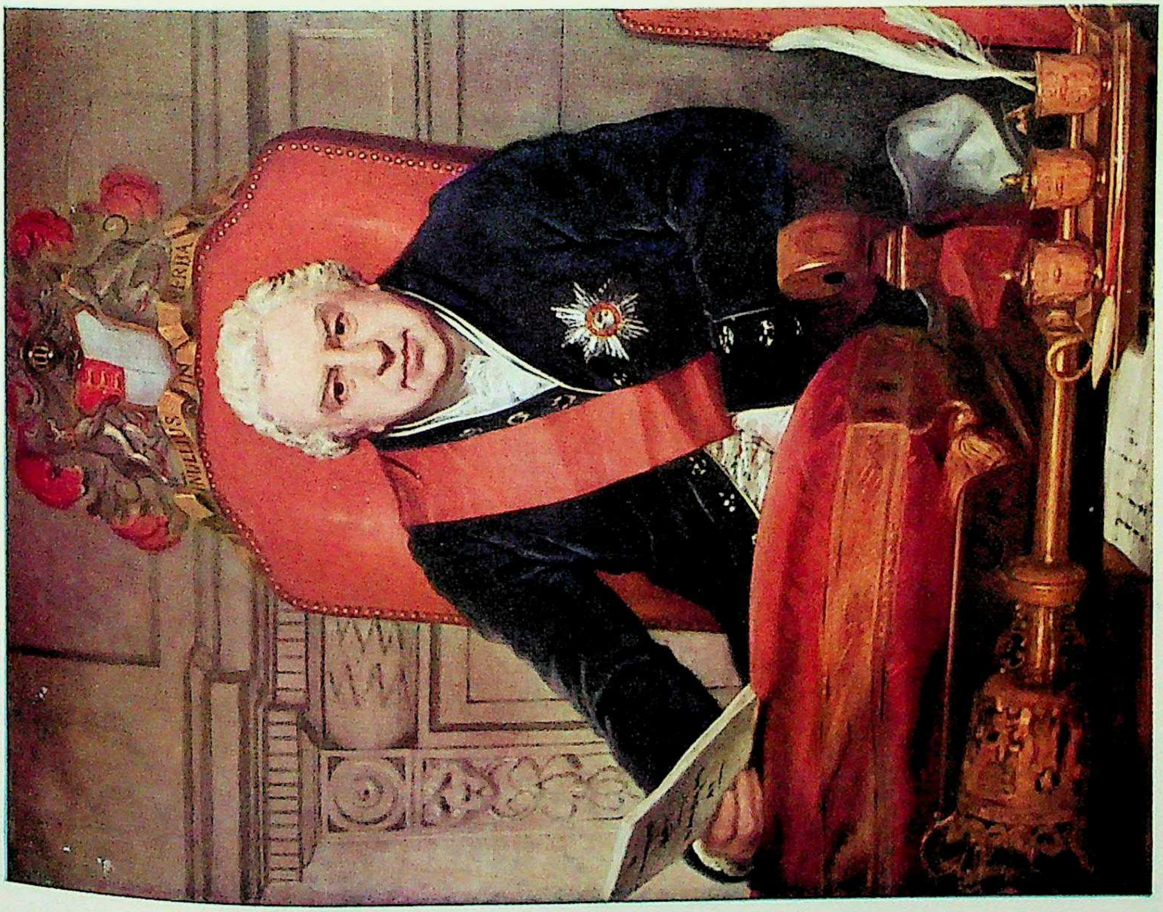
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PLATE 4 – *Sir Joseph Banks, President 1778–1820. By Thomas Phillips.*

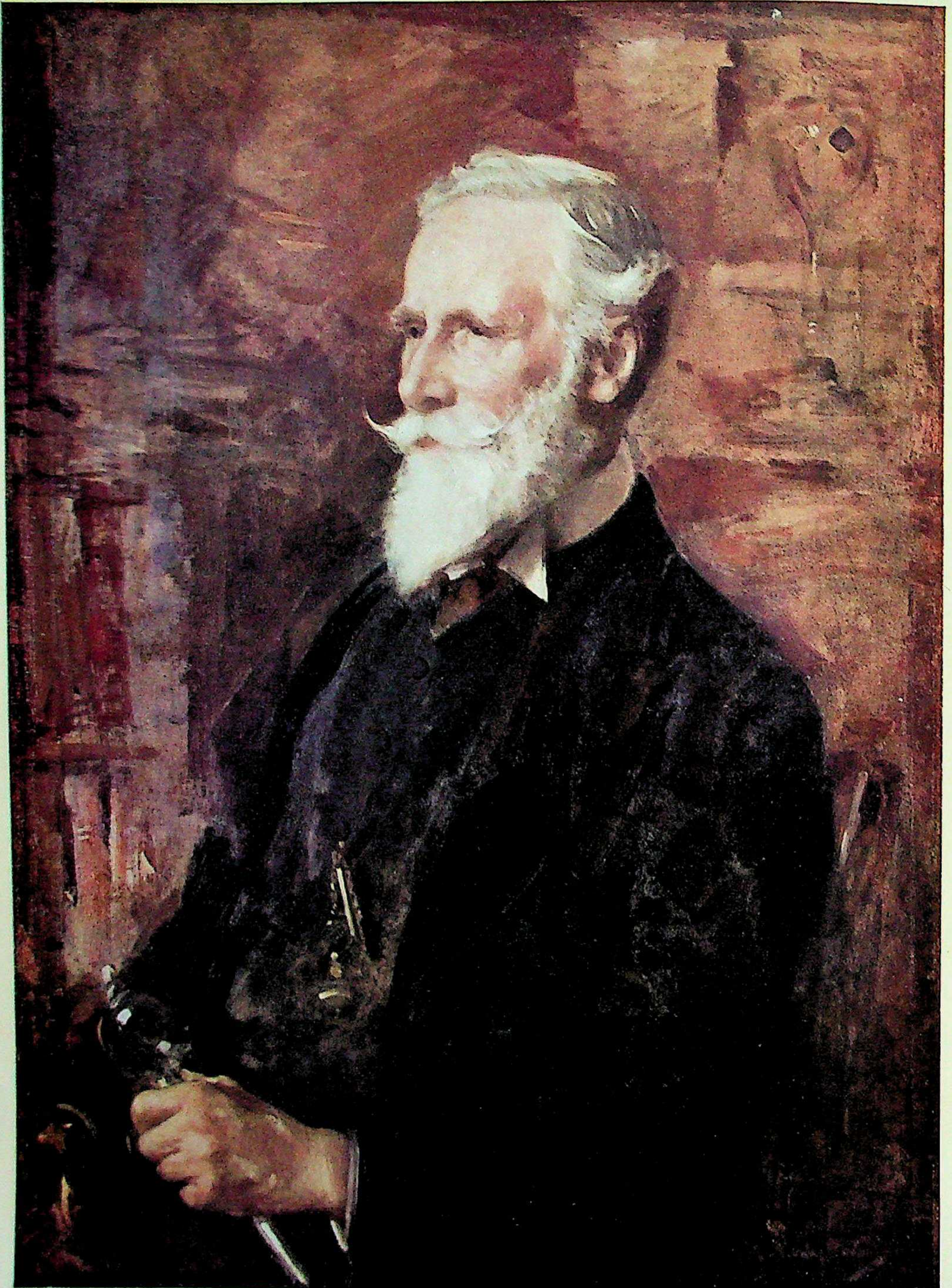

PLATE 6 – *Sir William Crookes, President 1913–15. By E. A. Walton.*

Parentalia, a history of the Wren family compiled by Christopher Wren, the son of Sir Christopher, and ought to have known; but in the book this portrait is not mentioned, and the attribution may not have been that of the donor. However, in a later, anonymous, edition, dated 1892, of the printed catalogue of portraits of 1892, the attribution is 'Sir P. Lely (? Sir G. Kneller)', while in the 1931 edition it is definitely set down as by Kneller. Yet in an edition of the Society's catalogue dated 1912 it is 'attributed to Michael Wright', a Scottish portrait painter who died in 1700.

Here are three attributions. However, as pointed out to me by Mr Oliver Millar, the portrait is almost certainly by J. B. Closterman, since an engraving from it by E. Kirkall, executed about 1730 and hence almost contemporary, so attributes it. Mr Millar suggests 1695 as the approximate date, later than a previous unsupported attribution of 1687. The date 1695 would make Wren's age at the time 63, which accords well with his features. The representation of St Paul's Cathedral in the background affords independent evidence on this point. The west towers are shown as planned at an early period, before they were raised on high pedestals with segmented arches, as first seen in an engraving of the design in 1702. The dome, which is shown nearly as executed, suggests a date not much before 1694, when the decision to proceed with the dome was taken. The design was still quite undetermined in 1690.[1] The Cathedral as shown offers, then, good reason for setting 1690–1702 as limiting dates.

A famous portrait, undoubtedly by Kneller, that emphasises, as does his Williamson, that outstanding scientific distinction was not in those days an indispensable qualification for President of the Royal Society, is that of Samuel Pepys, who reigned from 1684 to 1686 and put his *Imprimatur* on the manuscript of Newton's *Principia*, of which he undoubtedly could not have understood a word.

Between Wren and Pepys were two Presidents whose portraits are not in the possession of the Society, Sir John Hoskins, a lawyer, and Sir Cyril Wyche, politician and diplomat. Eight other Presidents (not counting Sir Robert Moray, President before the First Charter) are not represented, among whom are two whose absence must cause astonishment—George Biddell Airy, the great astronomer, who held office from 1871 to 1873, and Thomas Henry Huxley, 1883–85. After Huxley, all the Presidents answer the roll. Up to and including Gowland Hopkins, who held office from 1930 to 1935, it had long been the custom for the presidential portrait to be presented to the Society by subscribers; since that time the portrait has been commissioned by the Society.

After Pepys came five Presidents whose names, distinguished though they be, are little known for scientific accomplishment. Of two of them, Sir Robert Southwell and Lord Somers, there are Kneller portraits; of Charles Montagu, afterwards Earl of Halifax, Newton's friend and promoter, there is, strangely enough, no picture. Then, in 1703, the supreme Isaac Newton was elected to the Presidency, which he held to his death in 1727.

Of Newton there are three formal portraits in the possession of the Society. The earliest is by Charles Jervas, who was for a short time a pupil of Kneller's, painted in 1717, when Newton was seventy-four years old; the other two are by Vanderbank, one of 1725 and the other of 1726, and so painted not long before his death. The 1725 portrait was engraved by Vertue as a frontispiece to the third edition of the *Principia* (1726). There is a practically identical copy of this portrait at Trinity College, Cambridge.

All these portraits, then, represent Newton as an old and world-famous man, sedate, dignified, acclaimed, magistral, with his work accomplished and his sway supreme. They have been frequently reproduced. It is to be regretted that the Society does not possess, even in copy, a version of the Kneller portrait in the possession of the Earl of Portsmouth, showing Newton at about the time when the *Principia* was written, an impressive delineation of a face of dominating intelligence and strange, remote, almost hostile, genius. Recently (1950) the Society purchased a study in oils on paper executed by J. Vanderbank. It is, naturally, less formal and so in many ways more interesting than the final portraits. Quite apart from the fact that it shows the great man without wig, it bears the impression of a more direct transcription of a normal expression. It is reproduced, for the first time, in Plate 5.

Newton's immediate successor was Hans Sloane, about whose portrait by Kneller there can be no controversy, for Sloane presented it in his lifetime, after he had given up the secretaryship and before he became President. He was followed by Martin Folkes, whose portrait by Hogarth has already been mentioned. Contemporary opinion is summarized in the epigram:

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[1] I am indebted to Mr John Summerson, whose deep learning in matters pertaining to Wren's architecture is well known, for the facts here set down concerning the design.

'If e'er he chance to wake in Newton's chair
He wonders how the devil he came there.'

After five presidents little known today, of whom three presented their portraits, as was the custom, comes the redoubtable Joseph Banks, on many grounds an outstanding figure. He was President for forty-two years, a period far longer than the reign of any other President, Isaac Newton coming next with twenty-four years. He had sailed with James Cook in the 'Endeavour' as naturalist, bearing all the expenses of his staff and equipment, as his fortune allowed him to do. His rule as President was forceful and autocratic, but munificent. He was very proud of being made a Knight of the Order of the Bath. The Society portrait by Thomas Phillips, one of several of Banks which he produced, expresses well his personality. It shows him in the President's chair, in front of him the inkstand that will be familiar to Fellows, evidently ruling, and adorned with the star and ribbon of his Order.

The portrait of his successor, W. H. Wollaston, who among many outstanding feats can claim the discovery of rhodium and palladium, is well known and has often been reproduced. It is one of two painted by J. Jackson; Thomas Lawrence also executed one. Even better known, perhaps, is the three-quarter length of handsome, fashionably dressed, self-confident Humphry Davy by Thomas Lawrence, looking the observer squarely in the face. A figure of quite a different kind is the amiable Duke of Sussex, whose election must, I think, have been the last to be the subject of a contested ballot among the Fellows—and a closely contested ballot, for the Duke obtained 119 votes and Sir John Herschel 111. The portrait of the Duke is a typically competent one by T. Phillips, showing him wearing his star and ribbon of the Order of the Garter and a benevolent expression. There is a different version of it at the Reform Club.

A beautifully painted portrait, showing the quiet and perceptive mastery of his style, is that which Orchardson executed of Lord Kelvin in his old age (about seventy-five), four years after his retirement from the Presidency. The portrait of Lord Rayleigh by Sir George Reid is remarkable for being wider than it is high, an admirable composition in which the sitter is at his study table.

Among the portraits of Presidents of the present century one of the most striking is that of William Crookes by E. A. Walton. As in so many cases, it shows the subject as an old man—about seventy-nine in this case, with his most famous work well past—but an extremely striking and alert old man, grasping in his hand a Crookes tube of some kind. There is also in the Society's possession a very good bronze bust of Crookes, executed a few years earlier. It may be noted, incidentally, that while there is no portrait of Alfred Yarrow, Fellow and most generous benefactor, there is a bronze bust of him.

J. J. Thomson, Charles Sherrington, Rutherford, Gowland Hopkins, W. H. Bragg, Henry Dale, Robert Robinson, Lord Adrian are all represented by faithful portraits: that of Lord Adrian, whose term of office concluded last year, by A. R. Middleton Todd, a quiet but very faithful and understanding delineation, having just been suspended. In the portrait of Rutherford, which is a bold and successful representation of the great man in a characteristically informal pose and with a typical expression, scientific apparatus—that used for the identification of alpha particles as helium—is prominently introduced, an unusual feature in presidential portraits. But the most striking example of this is in the portrait of Gowland Hopkins by Meredith Frampton, where the subject, holding his little direct-vision spectroscope, is shown at work amid the typical tools of his craft. This picture is altogether in a lighter colour scheme than that of the general run of portraits and, as is bound to be the case with a highly individual piece of work, although generally admired has its critics among the Fellows. The writer is a whole-hearted approver, as he is of the very striking portrait of Robert Robinson by A. K. Lawrence, which when exhibited at the Royal Academy was one of the pictures of the year. This is in many ways a complete contrast with the Gowland Hopkins portrait, showing the subject in academic robes and more formal pose, if with a characteristic spread of fingers on the thigh. It is not, perhaps, the Robinson of the witty, incisive, casual conversation of his leisured hour, but it is very much Robinson the President, presiding on some serious occasion.

The portraits are not, of course, restricted to the Presidents, nor even to what would today be considered men of science. That of Henry More has already been mentioned. Until recently all the portraits were presented, and it would clearly be hard to decline a gift, especially if the donor were a forceful or influential figure. This may well account for the presence of some of the less appropriate persons, such as Samuel Chandler, officially listed as 'Dissenting Theologian', the same description being applied to Richard Price, whose portrait also hangs.

Among the non-presidential portraits are, however, those of some of the most celebrated figures in the history of science, starting with Robert Boyle, of whom there are two good and well known representations, one by Kerseboom and the other by John Riley. Strangely enough, both came into the possession of the Society long after the great man's death: they were presented in, respectively, 1765 and 1876. Another Original Fellow and early hero of the Society is John Wilkins, excellently depicted by Mary Beale: a third Original Fellow is the great mathematician John Wallis, whose portrait, by Gerard Soest, was presented just after his death in 1703. John Flamsteed, the first Astronomer Royal, looks sourly from the wall, as well he may, considering what he had had to put up with by the time he reached the age of 66 at which he was painted by T. Gibson. Of his successor, Edmond Halley, there are two portraits, one, by Thomas Murray, showing him as a bland youngish man in his own hair, and the other, by Michael Dahl, showing him as a grim old man of eighty, with formal wig. It is interesting to compare the two. James Bradley, his successor as Astronomer Royal, is another famous figure, excellently portrayed by Jonathan Richardson. The portrait of Jesse Ramsden, the great astronomical instrument maker, whose name is known to all students of elementary physics by the Ramsden eyepiece, is one of the few that show instruments in detail, the background being the celebrated five foot vertical circle that he made for the Palermo observatory. Ramsden is depicted as in a fur coat, in allusion, it is said, to the fact that he had lately completed a commission for the Czar of Russia. It is further recorded that the sitter, a plain-spoken Yorkshireman, did not approve and said that he had never worn such a thing in his life.

The painter of Ramsden is Robert Home, the brother of Sir Everard Home, who presented the picture to the Royal Society. Robert Home likewise painted, and Sir Everard presented, the well known portrait of John Hunter, the surgeon, who had married Home's only sister, with his peculiar dog. Robert Home later went to India, where he acquired considerable wealth as court painter to the King of Oude. Sir Everard Home, the first President of the Royal College of Surgeons, was a prominent Fellow, a Copley medallist, nineteen times Croonian Lecturer (easily a record!), and author of 110 papers in the Philosophical Transactions, which is possibly another record. It is said that he borrowed, in these matters, extensively from Hunter. His own portrait, by T. Phillips, he likewise presented to the Society.

To return to men of outstanding scientific fame, the portraits of Thomas Young and Charles Darwin are copies of well known works. That of Faraday is a vivacious representation of the great man at the height of his powers, by A. Blaikley. Less familiar are the features of Dalton and Joule, of whom the portraits in the Royal Society are by R. R. Faulkner and the Hon. John Collier respectively. There were portraits of both of these Manchester notables in the possession of the Manchester Literary and Philosophical Society, but they were lost when this Society's house was burnt down as a consequence of air attack on 23rd December 1940. The Joule seems to be the only painting of him now in existence. An impressive and interesting portrait is that of Benjamin Franklin by Joseph Wright (not the Joseph Wright whose dramatic 'Experiment with the Air-Pump' is now in the Tate Gallery, but an American-born artist, son of Patience Wright, who was well known as a modeller in wax). It would appear to be based on a painting by J. S. Duplessis, although this has been disputed.[1] The portrait by G. F. Watts of the chemist Thomas Graham gives him, perhaps, rather more of the Sir Galahad look than is indicated by that in the National Portrait Gallery.

The likeness of the aged, aged Fontenelle, elected a Foreign Member at the age of seventy-five, who, but for a few days, lived to be a hundred, looks sadly from the wall. It is a copy of a picture by Voiriot which would appear to have been painted well after his election. The mathematician Brook Taylor, known to students for 'Taylor's series', who, on the other hand, died young, appears in the Royal Society portrait, the only one known, as a bright and rosy face framed in a very high wig. Another great eighteenth-century mathematician of whom there is an arresting portrait is De Moivre, by Joseph Highmore. After studying this remarkable face it is not difficult to believe both that Newton in later life would refer questioners on difficult points in the *Principia* to De Moivre and that De Moivre knew the works of Molière and Rabelais almost by heart. About his love for the latter he must have been able to keep discreetly silent when necessary, for he was an intimate friend of the puritanical and serious Newton. This devotion to Rabelais is a trait that he shared with Benjamin Franklin. Malpighi and Meldola; John Herschel and Huggins; Lord Rosse, father of Charles Parsons of turbine fame (of whom the Society has no portrait), and Rumford are other figures who might detain us, were there time.

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[1] See C. H. Hart. 'Joseph Wright's Portrait of Franklin belonging to the Royal Society, London.' *Pennsylvania Magazine of History and Biography*. July 1908.

Among the portraits are further those of a number of outstanding investigators who were not Fellows of the Society. Some of these pioneers lived before the Society was founded, such men as Tycho Brahe, Copernicus, Descartes, Galileo, and William Harvey. The Copernicus, Descartes, and Galileo are acknowledged copies: the Tycho Brahe, presented by a Fellow, James Hodgson, in 1732, is ascribed to the celebrated portraitist M. J. Mierevelt, of whom it is written, without exaggeration, 'but comparatively few of the two thousand or more portraits that bear his name are wholly his own handiwork'. There is, not surprisingly, a portrait of Francis Bacon, for at the time of the inception of the Society he was so much considered a contributor to the foundation that his representation, with the words *Artium Instaurator* beneath it, is the most prominent figure in the frontispiece engraved by Wenceslaus Hollar for Sprat's 'History of the Royal-Society' (1667). It was presented by Martin Folkes in 1754: he was, no doubt, in sympathy with this early tradition. A portrait of Thomas Howard, Earl of Arundel, copied from a Van Dyck, was presented by Isaac Newton. The Earl died before the Society was founded, but the family was kindly disposed to the new body. For some years in its early days the Society met at Arundel House, and the building of a house for the Society was contemplated on a portion of ground offered by Mr Henry Howard, who in 1666 presented to the Society the valuable library known as the 'Arundel Collection'. Incidentally, most of these books, not of immediate scientific interest, were sold in 1924, the proceeds, some £6500, forming the Arundel fund, the income from which helps substantially to maintain the library.

The Arundel family may, then, well claim a place among the portraits. What, however, can be urged to justify space on the Society's walls for the portrait of the Scottish historian George Buchanan (1506–82) is not very clear, except that it was presented by Thomas Povey, a socially prominent Fellow, who frequently appears in the diaries of Pepys and Evelyn. Henry Spelman (1561–1641) is another historian whose presence is still harder to explain, for not even the donor is known. The painting is attributed to D. Mytens. The portrait of J. C. Sturm, the author of the popular *Collegium Experimentale*, who died in 1703, was presented by Theodore Haak in 1683. Theodore Haak, although a man of no scientific achievement, was an Original Fellow and took an active part in the proceedings that led to the foundation of the Society. His own portrait, an excellent piece of work, hangs on the wall. It is strange, then, that while he took sufficient interest in Sturm to present his portrait during his lifetime he never arranged his election as Fellow. It was not very difficult to enter the Fellowship in those days.

But the strangest of the non-Fellows to be present is, perhaps, Thomas Hobbes. In the years preceding the foundation of the Society he had had violent disputes with Seth Ward and John Wallis, who had exposed the absurdity of his mathematical lucubrations. John Wallis, already mentioned, was one of the ablest mathematicians of his day and took a very prominent part in the foundation of the Society, which Hobbes was not invited to join. In view of his scientific pretensions he much resented this exclusion: he attacked Robert Boyle and continued his futile controversies with Wallis until his death in 1679. He was, then, as far as science is concerned, a conceited and wrong-headed eccentric, an enemy to some of the chief promoters of the Society, and a bitter opponent of much pioneering scientific work of his time. Yet there hang prominently in the home of the Society two excellent portraits of him, one, attributed to J. B. Caspars, presented during his lifetime by John Aubrey, the author of the 'Brief Lives', a close friend of his, and a second, bequeathed by a non-Fellow of the Society in 1717, showing him as a much younger man. It is set down as from the brush of William Dobson, the doyen of English portrait painters, but is probably not by him. Aubrey says ' 'Twas pitty that Mr. Hobbs had not began the study of the Mathematics sooner, els he would not have layn so open. But one may say of him, as one says of Jos. Scaliger, that where he erres, he erres so ingeniosely, that one had rather erre with him then hitt the marke with Clavius.' Truly the whirligig of time brings in his revenges. It is, perhaps, fitting that this account should close with this outstanding example of the generosity and toleration of the Royal Society.

I am much indebted to Mr C. K. Adams, Director of the National Portrait Gallery, London, who kindly read through a draft of my article and gave me valuable information.

New kinds of macromolecules

C. E. H. BAWN

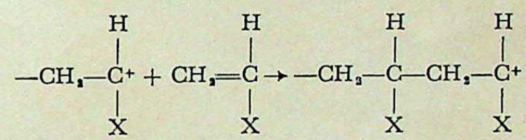
The past twenty-five years has seen immense progress in our understanding of the nature of macromolecules and in the development of general methods of synthesis. Recent research has led to the development of new synthetic methods which yield macromolecules of types not previously known and possessing combinations of properties indicating a wide range of practical applications for them. These developments have also very great theoretical significance.

High polymers are composed of chemical molecules very much larger in size than those occurring in the more familiar compounds of chemistry. The acceptance of this hypothesis some twenty-five years ago had a profound influence on the trend of research and was without doubt the major factor responsible for the immense progress in the study of macromolecules which has occurred in recent years. In spite of these developments the structures of the macromolecules which may be synthesized by present-day methods are still relatively simple compared with those found in naturally occurring high polymers like the proteins or polysaccharides. Recently, significant progress has been made in the synthesis of new kinds of macromolecules, and in this article some of this work will be briefly reviewed.

The formation of a macromolecule from its basic constituents depends on the setting up of a stepwise repetitive reaction in which the simple units are successively added to a growing molecule. Substances which undergo this kind of reaction fall broadly into two classes. The first comprises those in which the monomer units combine together in the presence of suitable catalysts without the formation of other products; this is known as addition polymerization. This process is largely confined to certain classes of unsaturated molecules, and polymer formation occurs by either a free radical or ionic chain mechanism. In the former case the chain growth process may be illustrated by the example shown below, in which R* is a free radical used as initiator.

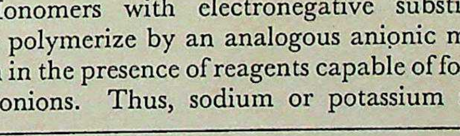
If the chains are long the formula of the polymer is an integral number of times the molecular formula of the monomer. Well known members of this class are polyethylene (X=H), polyvinyl chloride (X=Cl), and polystyrene ($X{=}C_6H_5$).

Certain vinyl monomers may be polymerized by very small amounts of catalysts of the type used in Friedel-Crafts reactions. Effective catalysts include $SnCl_4$, $AlCl_3$, BF_3, $TiCl_4$, and H_2SO_4, and by analogy with polar mechanisms of other reactions these polymerizations involve carbonium ions, the propagating step consisting of the addition of a monomer to a carbonium ion:



$$-CH_2-\overset{H}{\underset{X}{C^+}} + CH_2{=}\overset{H}{\underset{X}{C}} \rightarrow -CH_2-\overset{H}{\underset{X}{C}}-CH_2-\overset{H}{\underset{X}{C^+}}$$

The initiating reaction, which forms the carbonium ion, consists of the transfer of a proton or other cation to the monomer, and it is widely accepted that the catalyst is not effective without an added co-catalyst such as water, HCl, etc., for example:



$$BF_3OH_2 + CH_2{=}\overset{H}{\underset{X}{C}} \rightarrow CH_3-\overset{H}{\underset{X}{C^+}} + BF_3OH^-$$

*Iso*butylene, styrene, methyl styrene, dienes, vinyl alky-ethers, and cyclo-ethers are typical monomers readily converted to high-molecular polymers by the above catalyst types.

Monomers with electronegative substituents may polymerize by an analogous anionic mechanism in the presence of reagents capable of forming carbonions. Thus, sodium or potassium amide

$$R^* + CH_2{=}CHX \rightarrow RCH_2{-}CHX^* \qquad \text{Initiation}$$

$$\left.\begin{array}{r} RCH_2{-}CHX^* + CH_2{=}CHX \rightarrow RCH_2{-}CHX{-}CH_2{-}CHX^* \\ RCH_2{-}CHX{-}CH_2{-}CHX^* + CH_2{=}CHX \rightarrow RCH_2{-}CHX{-}CH_2{-}CHX{-}CH_2{-}CHX^* \end{array}\right\} \text{Propagation}$$

$$R(CH_2{-}CHX)_n{-}CH_2{-}CHX^* + R(CH_2{-}CHX)_mCH_2{-}CHX^* \begin{array}{l} \nearrow R(CH_2{-}CHX)_{m+n+2}R \\ \searrow R(CH_2{-}CHX)_n{-}CH{=}CHX \qquad \text{Termination} \\ \quad + R(CH_2{-}CHX)_mCH_2{-}CH_2X \end{array}$$

in liquid ammonia is particularly effective with acrylonitrile and methyl methacrylate, and metallic sodium with butadiene and isoprene.

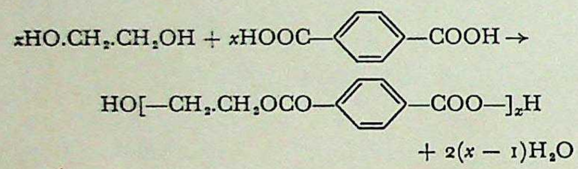
The second class consists of polymers which are formed from monomers bearing two or more functional groups which condense together, in successive stages, usually with the elimination of a small molecule (H_2O, CO_2, NH_3, etc.):

$$x\mathrm{HO{-}R{-}COOH} \rightarrow \mathrm{HO[{-}RCOO]}_{x-1}\,\mathrm{R{-}COOH} + (x-1)\mathrm{H_2O}.$$

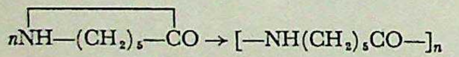
Important examples of this class are nylon 66, formed by the condensation of adipic acid with hexamethylene diamine:

$$x\mathrm{H_2N{-}(CH_2)_6{-}NH_2} + x\mathrm{HOOC{-}(CH_2)_4{-}COOH} \rightarrow \mathrm{H[{-}NH(CH_2)_6NHCO(CH_2)_4CO{-}]}_x\mathrm{OH} + 2(x-1)\mathrm{H_2O},$$

and Terylene (Dacron), formed by the condensation of ethylene glycol with terephthalic acid:



Polymer formation by an intermolecular condensation of bifunctional monomers may also be obtained by the addition polymerization of certain cyclic compounds, e.g. lactams, lactones, ethylene oxide, etc.:



$$n\mathrm{NH{-}(CH_2)_5{-}CO} \rightarrow \mathrm{[{-}NH(CH_2)_5CO{-}]}_n$$

The pattern of the polymer-forming reaction is thus simple, and in the resulting polymeric structure the structural units are connected one to another by chemical bonds in a linear sequence. It is the size and structural arrangement of the high polymers which endow them with their unique properties of high viscosity, tensile strength, toughness, elasticity, and deformability, and which distinguishes them from the more familiar simple molecules.

The nature of the polymer—whether it is rubber-like, plastic, or fibrous—is determined also by the detailed shape and chemical structure of the macromolecules. These factors determine both the regularity of the packing of the molecules and the strength of the forces holding the molecules together in the solid. Strong intermolecular action causes the long linear chains to pack together in an orderly array as in a crystal, and the polymer exhibits fibre-forming characteristics. At the other extreme, the inter-chain forces may be so weak that the chains can take advantage of their inherent property of flexibility and by virtue of free rotational movement around the connecting bonds can assume a coiled-up configuration. Stretching of the solid now favours chain alignment or crystallization, but on release of tension the chains return to the coiled-up state. This is the molecular picture of elasticity, and materials composed of molecules having these properties show rubbery characteristics. A gradual transition from fibrous to rubbery properties may be observed in a polymer when the ordered arrangement and linear symmetry of the molecule is destroyed by, for example, the introduction of bulky side groups on the main chain structure. In nylon the strong hydrogen bonding between the chains, which is responsible for the properties of this fibre, may be progressively reduced by replacement of the hydrogen atoms of the —CO—HN— groups by methyl (CH_3) groups, and there occurs at the same time a steady transition in properties from a crystalline fibre, through the rubbery state, to a viscous liquid of low melting point.

COPOLYMERS

The physical and mechanical properties of the polymer may also be materially modified by introducing a second type of monomer into the backbone structure. This may be accomplished by polymerizing a mixture consisting of two or more unsaturated monomers. The polymer formed is built up of units from each of the monomers and the 1 : 1 copolymer formed of the monomeric units A and B might be represented as follows:

. . . –A–B–B–A–A–A–B–A–B–B–A–B– . . .

The structure contains the units A and B arranged in a random manner. The composition of the copolymer and the relative distribution of the units along the chain is determined by the relative reactivities of the monomers. Certain pairs of monomers, for example allyl acetate and maleic anhydride, provide an exception to the above in that they react together to form the structure

. . . –A–B–A–B–A–B–A–B– . . .

in which the groups A and B alternate regularly. Apart from such special cases the methods of synthesis do not permit control of the exact arrangement of the monomer units, and only the average composition can be accurately specified.

Copolymerization destroys the regularity and symmetry of the main unit, and in a copolymer composed of constituents which differ geometrically, in polarity, or in other properties which determine intermolecular action, the possibility of the formation of ordered crystalline arrangements is considerably reduced. If one of the constituents is present in only small amounts in the copolymer, then sufficient sequences of units of one of the components may be present to maintain some degree of crystallinity. At the same time the effect of the addition of the second component is to reduce the melting point of the polymer, just as the melting point of a pure substance is lowered by a small addition of an impurity. Copolymerization therefore provides a powerful means of modifying and increasing the range of properties, and has been used extensively for the synthesis of polymers having to meet particular requirements. When copolymerized with acrylonitrile, polyvinyl chloride, which has a relatively low softening point, gives a fibre of higher softening point and a greater range of solubility. In contrast, vinylidene chloride is used as a copolymer with 15 per cent vinyl chloride added in order to lower its softening point and to reduce crystallinity. Similarly, the melting point of polyethylene terephthalate is lowered and its crystallinity decreased by copolymerization with aliphatic dibasic acids.

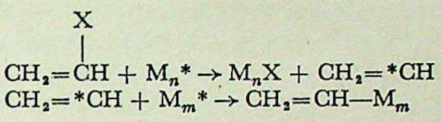
GRAFT AND BLOCK COPOLYMERS

It is clear that in addition to the random and alternating distribution of the structural units in a copolymer formed from two components A and B, other types of structure are possible. The most evident of these is that in which the units A and B are suitably ordered into long segments of uniform composition, namely

–A–A–A–A–A–B–B–B–B–B–B–B–B–A–A–A–A–.

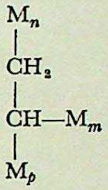
Copolymers of this type are known as block copolymers. A further modification of the copolymer structure arises when the second monomer is not incorporated in the main linear chain of A's but is attached to it by long or short side branches. This structure differs from any previously discussed in being non-linear, and many variants of the arrangement can be imagined. Thus the main backbone chain may itself be a copolymer of A and B and the graft formed with a third monomer, C, or the branch may be non-linear because of sub-branches. The properties of block and graft copolymers will be very different from linear copolymers made from the same pair of monomers, and the recent discovery of methods of synthesis of these kinds of structure is very important.

In the polymerization of a single vinyl monomer it is observed in some instances that the chain structure is occasionally interrupted by the formation of a branch. This is brought about by a chain transfer reaction during the polymerization, and involves the abstraction of an atom from the monomer molecule by the growing polymer radical M_n^*, for example:



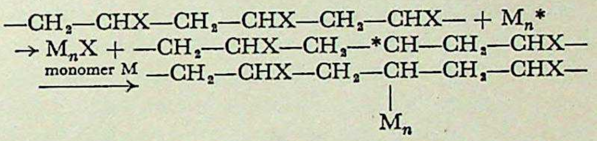
$$\begin{array}{l} CH_2{=}\overset{X}{\overset{|}{CH}} + M_n^* \rightarrow M_nX + CH_2{=}{}^*CH \\ CH_2{=}{}^*CH + M_m^* \rightarrow CH_2{=}CH{-}M_m \end{array}$$

The terminal unsaturated unit thus formed may be incorporated in the chain of another polymer molecule, when a branch results:



$$\begin{array}{l} M_n \\ | \\ CH_2 \\ | \\ CH{-}M_m \\ | \\ M_p \end{array}$$

In a similar way reaction between a growing polymer-free radical M_n^* and a preformed polymer molecule may lead to a branch in the following manner:



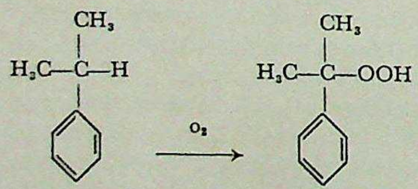
$$\begin{array}{l} {-}CH_2{-}CHX{-}CH_2{-}CHX{-}CH_2{-}CHX{-} + M_n^* \\ \rightarrow M_nX + {-}CH_2{-}CHX{-}CH_2{-}{}^*CH{-}CH_2{-}CHX{-} \\ \xrightarrow{\text{monomer } M} {-}CH_2{-}CHX{-}CH_2{-}\underset{\underset{M_n}{|}}{CH}{-}CH_2{-}CHX{-} \end{array}$$

Branching in simple vinyl polymerization is not very common, and with one or two exceptions is not important so far as polymer formation and properties are concerned. Polyethylene (polythene), made commercially by polymerization of ethylene at high pressures and at temperature above 200° C, has been shown to possess one branch for each 20–100 carbon atoms in the main chain. These branches appear to be short, although occasionally a long branch occurs. The extent of branching depends on the conditions of polymerization and is less the lower the temperature of the reaction. Branching in polyethylene is of technological importance, since it causes a considerable modification of the properties of the polymer. The melting point of commercial (branched) polythene is about 112° C compared with 135° C for the linear polymethylene ($(CH_2)_n$); the latter is considerably more crystalline.

The above concept of chain transfer in polymerization has recently been used in the synthesis of graft copolymers. If a polymer of one kind is dissolved in the monomer of another, which is then polymerized, chain transfer may occur between the growing chains and the already formed polymer chains. This produces a long-chain graft of one type of unit on the backbone of the polymer chain, and by the use of this method vinyl acetate, vinyl chloride, and styrene have been grafted on to polymethylmethacrylate and other polymers; methylacrylate grafted on to polystyrene; and styrene on to polystyrene [1]. When vinyl monomers are polymerized in the presence of rubber (polyisoprene) under suitable conditions some of the polymeric chains become attached to rubber molecules as a graft [2]. The product contains free rubber, together with a varying amount of free polymer formed concomitantly with the graft copolymer. In this way the properties of natural rubber can be widely modified. Some of the modified materials have unusual solubility characteristics, arising from the different behaviour towards solvents of the polymer and the rubber components of the molecule. Graft copolymers of styrene and methylmethacrylate with rubber can be readily compounded and cured to give light-coloured articles of good tensile strength, and with outstanding flex-cracking and fatigue resistance.

One of the difficulties in the use of the transfer method of grafting is that the branching on the chain occurs in a random manner, and the exact number and length of the branches cannot be controlled. Further, the homopolymer is formed together with the graft copolymer.

Another interesting method of making graft copolymers makes use of the ease with which certain hydrocarbon groupings can be oxidized to a hydroperoxide by air. Thus *iso*propyl benzene is readily oxidized by oxygen to the corresponding hydroperoxide:



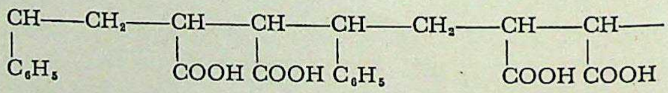
Peroxides of this type are well known and are extensively used to initiate free radical polymerization:

$$Fe^{++} + ROOH \rightarrow Fe^{+++} + RO^{-} + OH^{*}$$

These facts have been applied by H. Mark and his collaborators [3] to polystyrene. On oxidation, a hydrocarbon polymer such as polystyrene, or polystyrene alkylated with *iso*propyl groups, behaves in an analogous way and gives rise to a random distribution of hydroperoxide groups along the polymer chain. In the presence of Fe^{++} or other suitable redox activator, reaction of the above type occurs with the formation of radical centres on the chain only; when this reaction is carried on in the presence of another monomer, graft copolymers are formed. The graft copolymers of vinyl derivatives and acrylic esters so formed on the hydrocarbon backbone show extremely interesting properties. Vinyl alcohol branches, which may be readily formed by the hydrolysis of vinyl acetate branches, are soluble in water and are fully extended, whereas the polystyrene backbone, being insoluble, becomes highly coiled, although it is prevented from precipitating by the 'soluble' branches. When added to benzene this copolymer shows the reverse effect, and the vinyl alcohol branches are insoluble. If water is now added to this solution it is absorbed into the vinyl alcohol part of the polymer; similarly benzene can be brought into solution by water suspensions of the polymer. Suspensions of these copolymers are stable, and may have important uses as detergents, in emulsion paints, or for the surface treatment of fibres.

Alternative photochemical methods have been developed by H. W. Melville [4] and R. G. W. Norrish [5], using brominated polystyrene and polymethylvinyl ketone respectively. On photolysis, polymeric radicals formed by dissociation of the C—Br bond or the ketone grouping initiate polymerization of the added monomer.

Grafting on a preformed copolymer bearing functional groups may be carried out by a condensation reaction with a mono-functional unit. Thus, the condensation of the carboxyl group of the 1 : 1 copolymer of maleic acid and styrene—with primary and secondary alcohols overcomes the difficulty of isolation of the graft copolymer; in this way the effect of length of side chain from C_2 to C_{23}, and that of the degree of substitution of the carboxyl groups on the properties of the graft copolymer, have been measured [6].



$$\begin{array}{cccccccccccccccc}
CH & — & CH_2 & — & CH & — & CH & — & CH & — & CH_2 & — & CH & — & CH & — \\
| & & & & | & & | & & | & & & & | & & | & \\
C_6H_5 & & & & COOH & & COOH & & C_6H_5 & & & & COOH & & COOH &
\end{array}$$

The simplest and most direct method of synthesis of block copolymers is the direct scission of a polymer molecule A_n in the presence of a second monomer B. The scission gives a polymeric free radical which initiates the polymerization of the monomer B to form a product having one of the following structures:

–A–A–A–A–B–B– . . . –B–B
or A–A– . . . –A–A–B–B– . . . –B–B–A–A– . . . –A–A

It has been claimed that any method for producing rapid shear—such as ultrasonic absorption, cold milling or mechanical mastication, high-speed extrusion, or rapid shaking—will cause the break-up of polymeric molecules into radical fragments. The most successful application of this method has been the synthesis of block copolymers of rubber with neoprene, synthetic rubber GR–S, acrylonitrile rubber, and with certain vinyl derivatives, by cold mastication of a mixture of two rubbers or a rubber with a vinyl monomer [7].

Other methods of synthesis depend on growing one polymer to an appreciable length, but still retaining a free radical end, before bringing it in contact with a foreign monomer. In one method of doing this the polymerization of one monomer is initiated photochemically at some point in a capillary through which it is streaming before passing into a vessel containing the second monomer. If the time of flow between illumination and exit is shorter than the average lifetime of the polymer radical the active species will initiate polymerization in the second monomer. Block copolymers of butyl acrylate and styrene have been made in this way [8]. An alternative method involves the preparation of a polymer with end groups which can be dissociated into free radicals on illumination; for example, the photolysis in a second monomer (B) of a polymer A having CBr_3 terminal groups initiates the polymerization of the former. Block copolymers of styrene and methylmethacrylate have been so prepared [9]:

$$\text{Br–A–A–}\ldots\text{–A–A–CBr}_3 \xrightarrow{h\nu} \text{Br–A–A–}\ldots\text{–A–A–C–Br}_2{}^{*} + \text{Br} \xrightarrow{\text{monomer B}} \text{Br–A–A–}\ldots\text{–A–A–C(Br}_2\text{)B–B–B–B}$$

These methods produce the block copolymer in the presence of the two possible straight-chain copolymers, and consequently difficulties of separation arise. Also, the methods suffer from the disadvantage that only two blocks, one of each monomer or two of one and one of the other, are incorporated in the chain.

A more general method is that of linking together preformed polymers bearing functional end groups (—COOH, —OH, —NH_2) by polycondensation. The most complete study of this type is the work of D. Coleman [10] on the preparation of block copolymers of polyethylene terephthalate (Terylene, Dacron) (I) with polyethylene oxide (Carbowax) (II),

$$HOOCC_6H_4CO[OCH_2CH_2O\ CO\ C_6H_5CO]_nOCH_2CH_2OH \ldots\ldots (I)$$

$$HOCH_2CH_2O[CH_2CH_2O]_nCH_2CH_2OH \ldots\ldots\ldots (II)$$

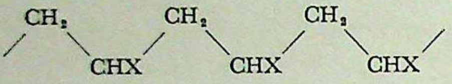
containing as much as 30 per cent by weight of modifying component. The copolymers showed striking properties. The crystallinity and high melting point remained almost unaltered; for example 30 per cent of polyethylene glycol of m.w. 2800 lowered the melting point only from 267 to 256° C. On the other hand, the flexibility, moisture recovery, and behaviour with dyes were considerably changed, but at the same time the tenacity and extensibility remained unaltered. These results indicated little alteration in the crystallinity,—a fact confirmed by the substantially unaltered X-ray photographs—showing that the polyoxyethylene segments were located in the amorphous regions. The latter were responsible for the increased water and dyestuff receptivity.

Theory shows that the melting point of the copolymer is determined by the molecular fraction of the ethylene terephthalate and not by the weight fraction. Thus, if the polyoxyethylene glycol has a molecular weight of 4000, then only 1 mole per cent of this component corresponds to 17 per cent by weight, and it is of great technical interest that amounts of this order can be incorporated into the polyethylene terephthalate without change of melting point. Block copolymers of this kind approach something which Mark has described as the 'ideal' in that they 'combine crystalline domains of high melting point and amorphous areas of low second-order transition'.

It has been suggested [11] that these novel types of block copolymers are probably fairly widespread in the field of proteins. Studies of the molecular constitution of silk fibroin indicate that the molecule contains two lengthy segments (about 170 Å long) which in contrast to the rest of the molecule carry bulky side chains which prevent their entry into the crystalline regions of the fibre. It has been suggested that the molecule may be represented as —C—A—C—A—C, where C represents readily crystallizable portions of the chain and A segments or blocks which constitute the non-crystallizing components.

ORIENTATED POLYMERS

A typically crystalline polymer is one in which the chemical and geometric structure is regular and there is no stereochemical irregularity. On the other hand, in non-crystalline polymers or copolymers there is either chemical or geometric irregularity or both. In vinyl polymers $(CH_2—CHX)_n$ in which the structural unit bears a single substituent X, chemical and structural investigations have shown that the common and preferred structure of the polymer chain is that in which the substituent X is attached to alternate carbon atoms in a head-to-tail arrangement:



Although each alternate carbon atom in the chain is a centre of asymmetry, the *d* and *l* forms would be expected to occur at random along the chain. Experimental results support this view, and numerous attempts which have been made to resolve polymer molecules of this type have been unsuccessful. This stereochemical irregularity in the chain is the cause of the infrequency of the occurrence of crystallization in polymers in which the substituent X is large.

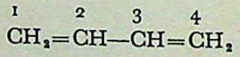
If the side group were regularly placed all on one side or successively in *d* and *l* configuration along the chain, a regular stereochemical pattern would result.

Recently, orientated polymers of this kind have been synthesized. G. Natta [12] has described the preparation of crystalline polypropylene, poly-α-butene, and polystyrene, and has suggested on the basis of X-ray diffraction evidence that these molecules are 'isotactic' and that in any one polymer chain, or at least in that forming part of a crystalline region, the substituent groups are identically placed, either all in the left-hand or all in the right-hand positions. These polymers were synthesized by a new type of catalyst which is believed to act heterogeneously and which directs the successive addition of monomer units to the growing chain in such a manner that long sequences of asymmetric carbon atoms having the same steric configuration are produced. The process is initiated, and probably occurs, at the catalyst surface, the growth reaction occurring by an ionic and not a free radical process. In all cases the isotactic polymer is formed together with the amorphous polymer, but these two forms may be separated by solvent fractionation. It has been claimed that certain specific catalysts give a 95 per cent yield of isotactic polymer with propylene. The use of these new catalysts has enabled the α-olefins to be polymerized to high molecular weight solids for the first time. Thus propylene may be polymerized at low pressures to give a crystalline polymer having fusion point 158–170° C and with good fibre-forming properties. Polystyrene, when normally prepared by free radical or cationic polymerization in the bulk or in solution, is a non-crystalline polymer with a heat distortion point of about 80° C. High molecular weight isotactic polystyrene is crystalline and fuses above 200° C. The solubility properties of the two polymer types are markedly changeable. Thus amorphous polystyrene having a molecular weight of one million is soluble in methyl ethyl ketone, whereas a crystalline polymer of the same molecular weight is insoluble. The mechanical properties of the polymer are drastically modified.

These interesting developments arose from the discovery of the so-called low-pressure ethylene polymerization process by K. Ziegler [13]. He showed that, using a catalyst formed by the interaction of aluminium triethyl, or other metallic alkyls, and certain metallic halides, such as titanium tetrachloride, suspended in a hydrocarbon, ethylene polymerized readily at ordinary pressures and temperatures to give a relatively unbranched polyethylene of high molecular weight. The new polyethylene has properties different from that of the material now in common use in that it has a much higher melting point, higher density, and greater crystallinity. In a sense, the low-pressure polyethylene can be regarded as an example of a polymer with a completely orientated structure, and the catalysts used in the preparation of the orientated hydrocarbon polymers described in the previous paragraph are of the same general type.

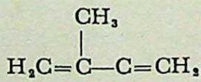
DIENE POLYMERIZATION

Normally the polymerization of 1 : 3 dienes such as butadiene (I) or isoprene (II)



$$\overset{1}{C}H_2=\overset{2}{C}H—\overset{3}{C}H=\overset{4}{C}H_2$$

I



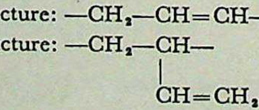
$$H_2C=\overset{\overset{\displaystyle CH_3}{|}}{C}—C=CH_2$$

II

leads to the formation of polymers having various structures and configurations according to whether addition occurs in the 1 : 4 or the 1 : 2 position:

1 : 4 structure: $—CH_2—CH=CH—CH_2—$

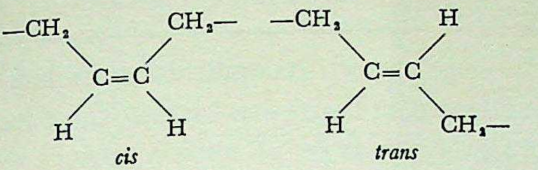
1 : 2 structure:



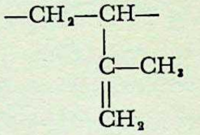
$$—CH_2—\underset{\underset{\displaystyle CH=CH_2}{|}}{CH}—$$

and in the polymerization of butadiene initiated by a free radical both types of addition occur, forming a structure which is very complicated.

Also the 1 : 4 unit may occur either as a *cis* or *trans* isomer:

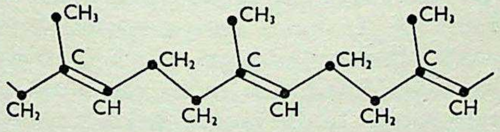


and the 1 : 2 units possess an asymmetric carbon atom which may give either *d* or *l* forms, as with the mono-substituted vinyl polymers. With the mono-substituted diene—isoprene—a further possibility of 3 : 4 structural chain units arises:

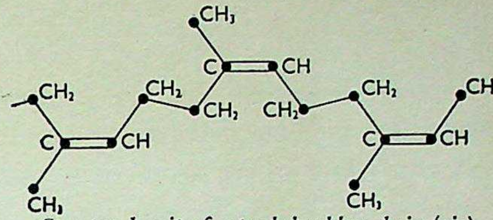


$$\begin{array}{l} -CH_2-CH- \\ \qquad\quad | \\ \qquad\quad C-CH_3 \\ \qquad\quad \| \\ \qquad\quad CH_2 \end{array}$$

in addition to 1 : 2 and 1 : 4 unions. Structural studies of polyisoprenes prepared synthetically, using free radical initiation, shows units of all the above types to be present in the molecule. Natural rubbers which are polymers of isoprene, on the other hand, conform to a regular structure in which only one type of structural arrangement is present in the chain. Thus Hevea rubber has a *cis* 1 : 4 structure and gutta-percha (balata) a *trans* 1 : 4 structure.



Structural unit of extended rubber chain (trans)



Structural unit of extended rubber chain (cis)

Highly significant examples of directed polymerizations have recently been observed with the dienes. Starting with isoprene, several methods have been announced for its polymerization to a *cis*-polyisoprene almost indistinguishable from natural tree-grown rubber. For the first time it appears that the method of the synthesis of rubber in nature has been closely approached. One of these processes uses a dispersion of 0·1 part of lithium metal for 100 parts of isoprene as catalyst [14], and other processes use catalysts of the Ziegler type [14].

Using selective heterogeneous catalysts Natta [12] has prepared polymers of butadiene in which polymerization occurred exclusively in either the 1 : 2 position or 1 : 4 *trans* linking. He has also synthesized a polymer with 1 : 4 *cis* linkings predominating. The 1 : 2 polybutadiene gives orientated fibres with properties similar to those of the isotactic polymers. Structure studies have shown that, unlike the isotactic polymers, the asymmetric carbons are substituted alternatively on the left and the right. These developments have opened a new chapter in the stereochemistry of the polymer molecule, which from both the theoretical and practical points of view is of immense significance.

REFERENCES

[1] HAYES, R. A. *J. Polymer Sci.*, **11**, 531, 1953.
SMETS, G. and WOODWARD, A. E. *Ibid.*, **14**, 126, 1954.

[2] BLOOMFIELD, G. F., MERRETT, F. M., POPHAM, F. J., and SWIFT, P. McL. 'Graft Polymers derived from Natural Rubber'. Third Rubber Technology Conference. London, 1954.

[3] MARK, H. *Angew. Chem.*, **53**, 67, 1955; *Text. Res. J.*, **23**, 294, 1953.
METZ, D. J. and MESROBRIAN, R. B. *J. Polymer Sci.*, **16**, 345, 1955.

[4] JONES, M. H., MELVILLE, H. W., and ROBERTSON, W. G. P. *Nature, Lond.*, **174**, 78, 1954.

[5] GUILLET, J. E. and NORRISH, R. G. W. *Nature, Lond.*, **173**, 625, 1954; *Proc. roy. Soc., A.*, **233**, 172, 1955.

[6] HUGLIN, M. B. University of Liverpool. (Private communication.)

[7] British Rubber Producers' Research Association. Annual Report, 1955, p. 23.

[8] MELVILLE, H. W. and HICKS, J. A. *J. Polymer Sci.*, **12**, 461, 1954.

[9] DUNN, A. S., STEAD, B. D., and MELVILLE, H. W. *Trans. Faraday Soc.*, **80**, 279, 1954.

[10] COLEMAN, D. *J. Polymer Sci.*, **14**, 15, 1954.

[11] COLEMAN, D. and HOWITT, F. O. *Proc. roy. Soc., A.*, **190**, 145, 1947.

[12] NATTA, G. *Makromol. Chem.*, **16**, 213, 1955.

[13] ZIEGLER, K. *Angew. Chem.*, **67**, 541, 1955.

[14] McSWEENEY, E. E. and KRAPA, E. L. *Ind. Eng. Chem.*, **48**, 22A, 1956.

Some aspects of luminescence

G. F. J. GARLICK

Luminescence is of great theoretical and practical importance—its applications include the cathode-ray tubes of television receivers and the fluorescent lamp—and has in consequence been very closely studied in recent years. Although there is as yet no unifying theory which satisfactorily covers all manifestations of the phenomenon, the energy-transfer processes, to which particular attention is paid in this article, provide a common link between them all.

The emission of visible light from a body on suitable excitation, e.g. by ultraviolet radiation or by cathode-ray bombardment, when the temperature of the body is well below that at which such emission would occur thermally, is known as luminescence [1–3]. The term is a generic one and covers a number of subsidiary phenomena. For example, it is convenient to refer to the emission during excitation as fluorescence and that persisting after cutting off the excitation as phosphorescence, or more simply afterglow. The latter is due to the slow release of energy stored, during excitation, in the form of excited electrons trapped in metastable states of the system. Afterglow of more than a millisecond duration is usually found only in solids, though there are some exceptions, such as the airglow in the night sky. In this article we are concerned with solid materials. When these are synthesized in the laboratory and show luminescence they are generally referred to as 'phosphors'. When heated in the dark after excitation some phosphors show one or more bursts of luminescence as the temperature rises. This phenomenon is known as thermoluminescence, or thermal glow. It is due to the thermal activation of electrons from metastable states. The quantitative measurement of its variation with temperature for a uniform rate of warming provides a very powerful means of studying the metastable states in phosphors, and was developed for this purpose in the writer's laboratory by Randall and Wilkins (see [3]).

When luminescence is produced by a particular form of excitation the term is given a suitable prefix, e.g. radioluminescence due to bombardment by nuclear particles; cathodoluminescence produced by a cathode-ray tube beam; and so on.

The applications of luminescence in such devices as the fluorescent lamp and the television cathode-ray tube screen are well known today [1–3]. Perhaps less well known are its applications in X-ray radiography, particularly in the recently developed image-intensifier tube and in the detection of nuclear radiation by the scintillation counter [4]. The simplest form of luminescent source is the electroluminescent lamp. The structure of this is shown schematically in figure 1(*a*); figure 1(*b*) shows a photograph taken by the light of such a lamp. In such a lamp the luminescent material or phosphor is embedded in a transparent dielectric between two electrodes, one transparent, to which the a.c. mains voltage is applied. The efficiency is low, as will be shown later, and hopes of an improvement are at present slender.

Besides being of interest in such direct applications, luminescence is a concomitant of phenomena in solid-state physics which are turned to practical account; examples are the photographic process in silver halides at low temperatures [5], and charge-carrier injection in the crystal triode valve, or transistor. It occurs during certain chemical reactions (chemiluminescence); such reactions are of particular interest in living organisms (bioluminescence). In the present article we shall be concerned with an important process underlying all these phenomena and their applications, namely the transfer of energy—and particularly the efficiency of transfer—through a crystal or large molecule from the time of its absorption to its re-emission as luminescence. The inorganic phosphors are considered first, with particular reference to their performance in such devices as the fluorescent lamp and the cathode-ray tube.

ENERGY TRANSPORT IN INORGANIC CRYSTALLINE PHOSPHORS [1, 3]

There are two main categories of inorganic phosphors on which interest is now centred: those in which luminescence is accompanied by photoconductivity—i.e. excitation produces free-charge carriers in the phosphor crystals—and those in which transport of energy in the crystals is an essential part of the luminescence process but takes place without the movement of charge.

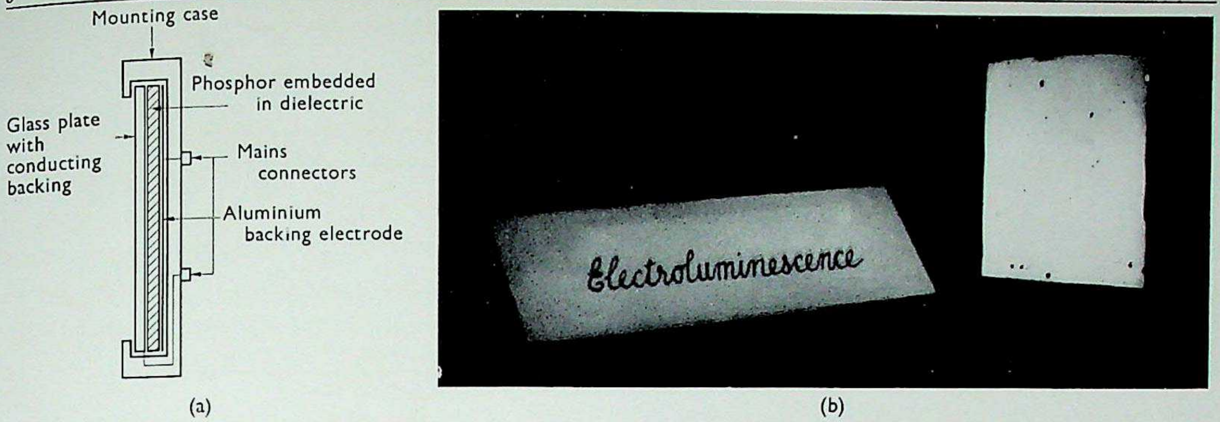

Mounting case
Phosphor embedded in dielectric
Glass plate with conducting backing
Mains connectors
Aluminium backing electrode
Electroluminescence
(a)
(b)

FIGURE 1 – *(a) Schematic diagram of an electroluminescent lamp. (b) Photograph of lamp by its own emission. (Exposure time ~ 1 min. on rapid process plate.)*

(a) Photoconducting phosphors

Photoconducting phosphors, such as zinc and zinc cadmium sulphides, are the usual screen materials for television cathode-ray tubes. Their ultimate efficiency depends on the return, without loss, of the electrons liberated in the crystals by the primary excitation to specific centres where luminescence emission can take place. These centres are produced by including suitable impurities during the preparation of the phosphor. To explain the functioning of such phosphors one must examine the energy states for electrons in the crystals. These are shown in figure 2(*a*), the energy being plotted against a directional co-ordinate in the crystal. The possible energies for electrons in the host crystal are restricted by quantum laws, but fall into bands of allowed values separated by zones of forbidden values; this is distinct from the discrete states for electrons in isolated atoms, shown schematically in figure 2(*b*). These energy levels extend throughout the lattice, and so the electrons in them are not spatially localized.

Inclusion of impurities or crystal defects (such as vacant lattice sites) gives rise to localized levels in forbidden zones, as shown in figure 2(*a*). In luminescence we are ultimately concerned with the highest energy band which is filled by the original valence electrons of one of the lattice constituents; the next highest allowed energy band, which is empty; and the localized impurity centres or defect levels in the forbidden zone between these bands. Cathode-ray excitation (or excitation by ultra-violet radiation of sufficiently short wavelength) results in the raising of electrons from the filled band F to the empty or conduction band C. Empty levels are left behind in the valence band, and it can be shown quantum-mechanically that this is equivalent to having positively charged electrons in this band. These are called positive holes, because they are the result of the creation of vacant electron levels in the band. These positive holes can move through the crystal, as do the conduction electrons, under the influence of an applied electric field, but in the opposite direction to that of the electrons. The positive holes usually have a lower mobility than conduction electrons. On reaching occupied luminescence centres L they will capture electrons, thus emptying the centres and making them available for recombination of conduction electrons and radiation of the excess electron energy as luminescence. Thus in this case positive hole migration promotes luminescence efficiency. However, if conduction electrons are captured in lattice defect levels T (called electron traps), then the immobilized electrons will attract free positive holes and recombine with them, dissipating their excess energy thermally in the crystal lattice. This process offsets that of luminescence and, as shown by the author [3], it is, apart from secondary electron emission loss, the chief hindrance to the attaining of the theoretical maximum of efficiency in cathode-ray tube screens.

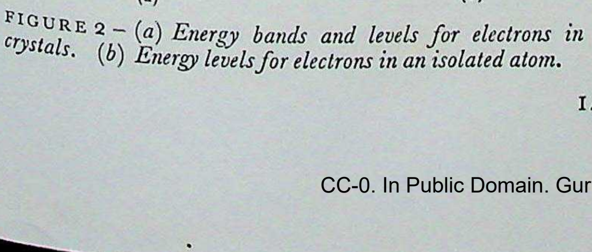


FIGURE 2 – *(a) Energy bands and levels for electrons in crystals. (b) Energy levels for electrons in an isolated atom.*

It will be seen that trapping effects, which are usually responsible for the afterglow of phosphors by their storage and subsequent release of electrons, are a disadvantage to the efficiency of cathode-ray tubes. Commercial phosphors can now be made with an efficiency of 25 per cent for cathode rays; this means that three times the light-emission energy of the television screen is wasted, about half of it in warming up the screen. This has a further adverse effect on efficiency, since above a certain value this decreases with rise in temperature. Taking into account secondary emission losses, it may not be possible to exceed an ultimate efficiency of about 50 per cent for cathode-ray tube screens, however good the phosphor is.

(*b*) *Non-photoconducting phosphors* [1, 6]

Phosphors used for the internal coating of fluorescent lamps depending on low-pressure discharge are known as 'sensitized' phosphors. The main impurity used to activate the visible luminescence does not directly absorb the 2537Å radiation—the main effective radiation of discharge in mercury vapour—nor does the crystal lattice. To effect absorption and subsequent emission from the main activator a sensitizing impurity is introduced which has an absorption band at 2537Å and itself gives visible luminescent emission, usually at shorter wavelengths than that emitted by the main activator. The colour rendering of the lamp thus depends on the choice of the main activator and sensitizer, although in many cases alteration in lattice constitution can alter the relative intensities of the emission bands and so act as a convenient third variable for colour control. In the calcium halophosphates, for example, antimony is used as the sensitizing impurity, with manganese as the other activator impurity. The fluoride : chloride ratio in the halophosphate lattice serves as a secondary control of the colour of the light.

Figure 3 is a schematic spectral diagram for a typical lamp-phosphor. The fundamental problem involved here is the way in which, after absorption of radiation of wavelength 2537Å, the sensitizer atom S hands over the absorbed energy to the other activator A. This in fact takes place by a quantum-mechanical resonance process between sensitizer and sensitizer until it occurs between a sensitizer S and an activator A. If the excited sensitizer atom and a neighbouring unexcited atom (which may or may not be a sensitizer atom) can have the same energy in their excited states then there is a finite probability that a transfer of all the energy will occur between excited and unexcited atoms. This process will go on between sensitizer atoms until the energy is degraded by a luminescence transition in the sensitizer or until a transfer to an activator occurs, a degradation can then occur by a luminescence transition in the activator atom. In some cases, e.g. calcium orthophosphate with cerium as sensitizer and manganese as activator, the distance over which S to S and S to A transfer is possible has been calculated from experimental data. Transfer may take place from a sensitizer to another sensitizer at any one of 150 neighbouring lattice sites. For S to A transfer the number is lower, namely 30, but in both cases the energy transfer is over distances much greater than those for adjacent lattice positions.

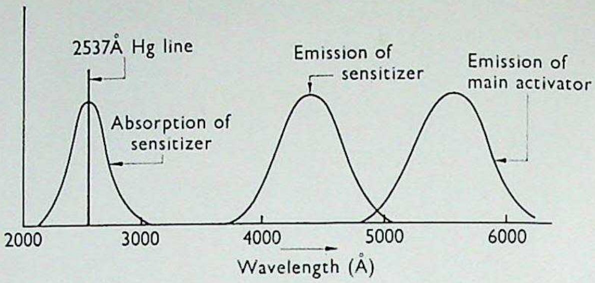


FIGURE 3 – *Schematic absorption and emission spectra for a fluorescent lamp phosphor.*

The efficiency of transfer can be markedly impaired, and of course both the efficiency and the colour of the lamp will then suffer, by the presence of 'quenching' impurities in which non-radiative degradation of the absorbed energy can occur. However, in spite of the need for great precision in choosing the ratios of sensitizer and activator atoms and of finding the right kind of host lattice, the modern fluorescent lamp is approaching the theoretical limit of its efficiency (see table, p. 147).

(*c*) *Electroluminescence* [1]

Figure 4 shows the energy band system in the phosphor crystals at one peak of the voltage cycle for the lamp illustrated by figure 1(*a*). A high field ($\geqslant 10^7$ V/cm) builds up at one side of the phosphor, and this is sufficient to eject electrons from normal states in centres into the conduction band. They are accelerated in the high-field region and produce further excitation by ionizing collisions, and by recombination cause emission of luminescence. The potential barrier picture shown reverses itself in each voltage cycle. For this kind of lamp special phosphors of the zinc sulphide class have been devised; they have a relatively high content of copper impurity and

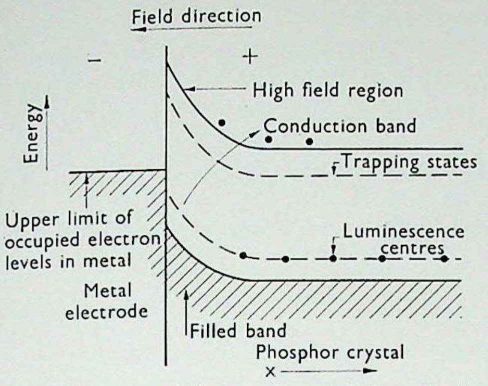


FIGURE 4—*Energy band diagram for metal-electroluminescent crystal contact at peak applied voltage (metal negative).*

their working efficiency is good. However, because of the fundamental nature of the electroluminescent process, efficiencies of more than a few per cent are hardly likely.

Another form of electroluminescence is that occurring when charge-carriers are injected into germanium or silicon carbide; the particular carriers represent only a small proportion of the total material. An example is injection of positive holes into germanium which is N-type, i.e. in which the normal electrical conductivity is predominantly due to electron motion through the crystal rather than to positive hole movement. When hole conduction is dominant the material is referred to as P-type. The injected carriers combine with those of opposite sign, giving up their energy as radiation. The process may take place through impurity centres. In some specimens emission due to hole injection has been observed as far into the infra-red as 60 000Å. However, currents of many milliamperes must be injected in order to observe the emission, which has a very low efficiency.

The accompanying table summarizes the performance and intrinsic efficiencies of the three light sources discussed above; figures are also given for an ordinary tungsten filament lamp.

Light source	*Intrinsic efficiency (per cent)*	*Theoretical limit of efficiency (per cent)*	*Practical efficiency in lumens/watt*
Cathode-ray tube screen	25	75	up to 100
Low-pressure fluorescent lamp	~ 60	80	> 60
Electroluminescent lamp	~ 1	—	5–10
Tungsten filament lamp (gas-filled)	~ 2	—	10–15

LUMINESCENCE IN ORGANIC CHEMICAL SYSTEMS [3, 7]

In organic systems, ionizing processes in excitation are in general injurious to the luminescence processes. However, for both high-energy particles and ultra-violet excitation of compounds, such as the crystalline aromatic hydrocarbons and their solutions, the luminescence process can be quite efficient and can involve large transfer of energy through the system, often by a process similar to that for the sensitized inorganic phosphors discussed above. An example is provided by crystalline naphthalene containing a trace of anthracene. Absorption at shorter wavelengths in the naphthalene absorption bands is followed by almost complete transfer of the energy to the anthracene molecules, with subsequent emission as luminescence characteristic of these molecules. Again a quantum-mechanical resonance process is involved. In crystals, absorption in the molecular-absorption region of the spectrum produces photoconductivity. In anthracene the carriers appear to be positive holes. In liquid solutions, such as *p*-terphenyl in xylene, the solute molecules receive the energy absorbed in the xylene, but probably not by a resonance process. Each excited solvent molecule moves about until it collides with a solute molecule and hands over its excitation energy.

When larger, more complex, molecules are considered the exact interpretation of effects becomes very difficult. Examples are the luminescence of chlorophyll during the photosynthetic processes and the oxidation of luciferin in the firefly and other luminescent species [8, 9]. However, there is a possibility of applying theories developed for resonance transfer in the simple organic compounds to these biological systems. The fluorescent Scheibe polymer threads offer controllable material with large dimensions (thread length ~10^3Å); this lends itself to exact study and may provide a link between the simple molecules and the luminescent substances of plants or animals.

DETECTION OF NUCLEAR PARTICLES [4]

Some of the early studies of nuclear particles were made by Rutherford with a form of the Crookes' spinthariscope; this had a luminescent screen in which alpha particles produce scintillations which can be viewed through a lens. A combination of a single-crystal phosphor and a photoelectric multiplier constitutes the modern form of the device (figure 5). The ultimate performance of such scintillation counters is set by the conversion efficiency of the phosphor and by the photoelectric efficiency of the multiplier. The phosphor efficiency depends on the nature of the particles or radiation being detected and particularly on the density of ionization produced. Inorganic crystals of the photoconducting type, in which—as shown above—the luminescence process is dependent on carrier liberation and transfer, will show approximately the same response for lightly as for densely ionizing particles. In contrast, in non-photoconductors, particularly organic crystals and solutions, ionization is deleterious to the luminescence process, which involves the resonance or collision transfer of energy respectively. Thus densely ionizing particles (protons, alpha particles, and so on of a few MeV energy) produce scintillations in these phosphors rather inefficiently. In addition, by their collisions with, and displacement of, the lattice atoms and by production of chemical dissociation as a result of the ionization, the phosphor is permanently damaged, its efficiency diminishing with dosage. The scintillation counter is notable for the speed of its response, the 'dead time' being in some cases less than 10^{-8} second.

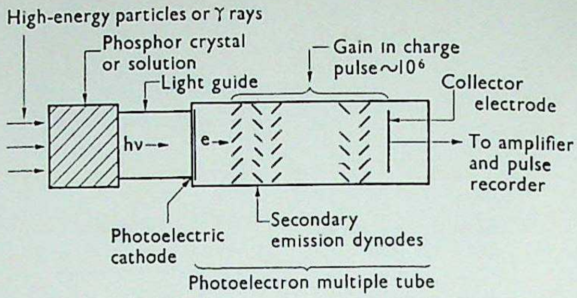

High-energy particles or γ rays
Phosphor crystal or solution
Light guide
Gain in charge pulse~10^6
Collector electrode
hν
e
To amplifier and pulse recorder
Photoelectric cathode
Secondary emission dynodes
Photoelectron multiple tube

FIGURE 5 – *Schematic diagram of a scintillation counter for nuclear particles and radiation.*

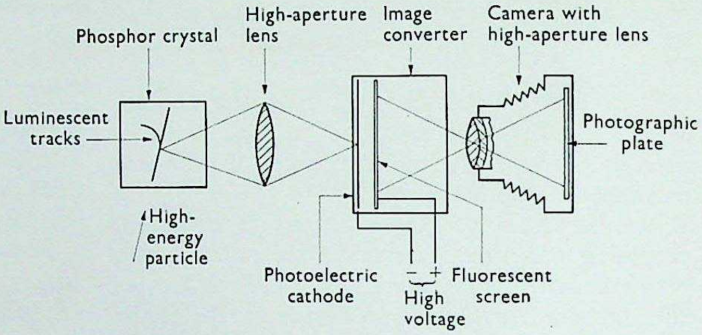

Phosphor crystal
High-aperture lens
Image converter
Camera with high-aperture lens
Luminescent tracks
Photographic plate
High-energy particle
Photoelectric cathode
High voltage
Fluorescent screen

FIGURE 6 – *Schematic diagram of luminescent 'cloud' chamber.*

Recently Russian workers [10] have applied phosphor crystals to nuclear particle detection in a somewhat different way, as solid 'cloud' chambers for observing the particle trajectory. A form of this apparatus is shown schematically in figure 6. The particles are incident on a luminescent crystal and produce tracks of light within it. For very fast particles (such as high-energy protons) mesons may be produced in the crystal, and the 'stars' familiar in photographic emulsions used as detectors for cosmic rays can be obtained. The luminescent track is focused by a wide-aperture lens L on to the photocathode of an image converter I. The photoelectrons released in the latter are accelerated to high energies and impinge on a fluorescent screen to produce an image of the track in the crystal. The image converter provides the high gain necessary to observe the track. In the Russian form of the chamber a caesium iodide crystal with thallium impurity is used as detector.

CONCLUSION

It is clear to those working in the field that there is no comprehensive theory of luminescence covering all its mechanisms in liquids, gases, and solids and in biological systems. However, the problem of energy transfer processes provides a common, though as yet tenuous, link between them and determines their practical performance.

REFERENCES

[1] Luminescence (a symposium on the present problems with reference to applications). *Brit. J. appl. Phys., Suppl.* 4, January 1955.

[2] Leverenz, H. W. 'Luminescence of solids'. John Wiley and Sons Limited, New York. 1950.

[3] Garlick, G. F. J. 'Luminescent Materials'. Oxford University Press, London. 1949.

[4] Curran, S. C. 'Luminescence and the scintillation counter'. Butterworth's Scientific Publications Limited, London. 1953.

[5] Fundamental mechanisms of photographic sensitivity (Conference Proceedings, Bristol, 1951). Butterworth's Scientific Publications Limited, London.

[6] Botden, T. P. J. *Philips Res. Rep.*, 7, 197, 1952.

[7] Forster, T. H. 'Luminescence in organic systems'. Göttingen. 1951.

[8] Newton-Harvey, E. 'Bioluminescence'. Princeton, New Jersey. 1952.

[9] 'Luminescence in biological systems'. *Conf. Amer. Ass. Adv. Science*, 1955.

[10] Plakhov, A. G. and Butslov, M. M. *Dokl. Akad. Nauk. S.S.S.R.*, **100**, 241, 1955.

The study of organic evolution by observation and experiment

E. B. FORD

The Darwin Wallace Lecture of 1858 established evolution as the basic concept of biology. Only since the first war, however, has the process of evolution been observed and studied in natural populations. Indeed, the combination of ecological and genetic methods which has made this possible did not, for a considerable time, attract many research workers outside the small and scattered group who developed them in their early stages.

The occurrence of evolution, either in the immediate past or still in progress, can be inferred indirectly from the differences which exist between one and another population of plants and animals. Sometimes these are obviously related to the conditions of the habitats, more often their significance is obscure because we do not know enough of the genetics and ecology involved. For instance, a selective change has affected the Fool's Parsley, *Aethusa cynapium*, when growing in stubble-fields. Here it is smaller and flowers later than elsewhere, for the flowering heads of the normal strain are cut off by the reaping machine. We do not yet know the genetics of this situation, though we can be reasonably certain that the characters involved are polygenic. On the other hand, banded specimens of the Mottled Beauty moth, *Cleora repandata*, are in Britain almost confined to the west, where in some districts they comprise over 20 per cent of the population. The insect occurs in woods all over the country, but the banded pattern is unknown in the south-eastern counties. It is produced by a single gene incompletely dominant in effect, but there is nothing to indicate why its occurrence is related to certain areas.

The evolutionary divergence of a population into distinct races nearly always requires some form of isolation, as Darwin himself recognized, but the way in which this operates is a subject of acute biological controversy even today. In the first place, it is generally agreed that the subdivision of a population into small isolated units favours rapid evolution. This can usefully be illustrated by an example drawn from work on the Meadow Brown butterfly, *Maniola jurtina*, in the Isles of Scilly and elsewhere. In this insect the number of spots on the underside of the hind wing varies from 0 to 5. Their frequency-distribution in the males is everywhere the same, having a single mode at 2 spots (figure 1). In the females, however, it has widely different values from one island to another, though, with a single exception to be noticed later, on each it has retained its characteristic form season after season.

The butterfly has been studied on five 'small' and on three 'large' islands in Scilly: the difference in area between the two groups is considerable, being seventeen times or more. The female spot-distributions are similar on all three large islands, the curve being approximately flat-topped with high frequencies at 0, 1, and 2 spots (figures 2–4). Yet they differ widely from one to another of the small islands: being unimodal at 0 or at 2 spots, or bimodal at these values (figures 5–7), while the modes may be greatly, or relatively little, accentuated. The similarity of the various large island populations and the dissimilarity of the small island ones has been explained in three ways.

It has been suggested that segregation in the genes which control spotting does not significantly affect individual survival, and that their chance distribution has produced differences in the small populations, which it could not do in the large ones. This is the concept of 'random drift', which has been advanced by Sewall Wright and others, chiefly in America. It is, in fact, of negligible importance in evolution; it is certainly not responsible for the situation just described, and this for several reasons. It can be calculated that random survival can outweigh the effects of selection only in small communities of a few hundred or less. None of the small islands in question carry populations of less than a thousand, and on several of them the total amounts to 18,000 or more. It has also been shown by R. A. Fisher [1] that gene substitutions of effectively neutral survival-value must be very rare. In the present instance, the observed stability of the spot-distribution on each

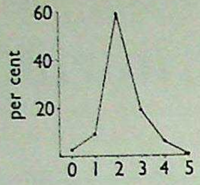


FIGURE 1 – *Distribution of spotting in male Meadow Browns.*

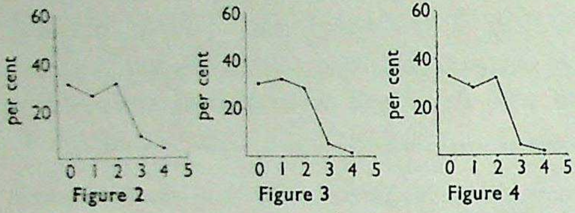


Figure 2 Figure 3 Figure 4

FIGURES 2–4 – *Distribution of spotting in female Meadow Browns on three large islands. Figure* 2, *Tresco; figure* 3, *St. Martin's; figure* 4, *St. Mary's.*

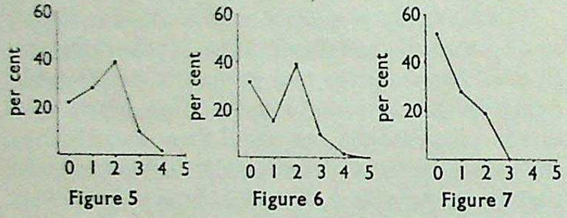


Figure 5 Figure 6 Figure 7

FIGURES 5–7 – *Distribution of spotting in female Meadow Browns on three small islands. Figure* 5, *St. Helen's; figure* 6, *Tean; figure* 7, *White Island.*

small island is wholly inconsistent with the suggestion that this is subject to random drift.

Secondly, the theory has been advanced that at some period in the past the Meadow Brown may have become so rare in Scilly that the numbers on the small islands were reduced to a few specimens only. The chance characteristics of these individuals might then determine the type of population to be derived from them, while on the large islands enough specimens might remain to preserve the original characteristics of the race. However, that view does not appear to be tenable. First, if the various small island races reflect the chance qualities of a few butterflies surviving a former period of extreme scarcity, the genes responsible for spotting are not controlled by selection; and some of the difficulties inherent in such a concept have already been outlined. Secondly, one of the Meadow Brown populations on a small island (Tean) has been subject to a marked ecological change since our investigations began and to this it has evidently adjusted itself, for it is the only one in which the frequency-distribution of spotting has altered to an extreme degree. But reduction to very small numbers, and subsequent repopulations from the survivors, was not needed to produce that change, for we studied the population throughout the period in question and we know that nothing of the kind took place.

Thirdly, when a population is subdivided into a number of small isolated groups, each can be adapted by selection to its particular local environment. But when continuous and occupying a larger area it can be adjusted only to the average of the conditions to which it is exposed. Such averages will vary relatively little from one large community or neighbouring island to another. This is the chief reason why isolation into small colonies favours rapid evolution, and it appears to be the one responsible for the similarity of the Meadow Brown butterflies on the large islands of Scilly and their dissimilarity on the small ones. The rapid adaptation to changing ecological conditions already mentioned favours such a view [2].

These alternatives are now being investigated experimentally. Over a hundred fertile females derived from a large island (St Martin's) have been used to found colonies on two small ones from which the insect was absent. Study of them in a few years, if they survive, may provide decisive evidence in favour of one of the theories here outlined.

Two subjects mentioned in connection with the Meadow Brown populations on Scilly deserve further comment. They can best be discussed with the help of examples. The Scarlet Tiger moth, *Panaxia dominula*, is a single-brooded species flying in July. It occurs commonly over about fifteen acres in a marsh near Oxford. The foodplant is Comfrey, *Symphytum officinale*, and the insect is restricted to the locality by surrounding woods and agricultural land. In this marsh a variety, *medionigra*, very rare elsewhere, is not uncommon. It is a heterozygote, the homozygous mutant, *bimacula*, being a much more extreme form. Both are characterized by an excess of black pigment, and, since all three genotypes are visibly distinct, the gene-frequency can be calculated by appropriate sampling. This has now been done each season since 1939: the gene has shown considerable fluctuations in frequency, on the whole declining from 9·2 to 1·0–2·0 per cent of the population. At the same time, the population-size has been calculated by the method of marking, release, and recapture.

With Mendelian inheritance it is possible to calculate the chance that a given change in gene-frequency is due to random sampling if the size of the population be known, and in this instance the relevant data are all available over a long period. The result shows that the observed seasonal fluctuations in the occurrence of the *medionigra* gene are much too great to be ascribed to random survival, and must be due to selection, varying in intensity and direction from year to year. Thus in the first instance in which the possibility of 'random drift' can be directly assessed as an evolutionary agent, it can be decisively excluded.

An unexpected discovery has been made by P. M. Sheppard which throws some light on the maintenance of genetic diversity at the *medionigra* locus. In the laboratory, and presumably also in the wild, mating is not at random, but is influenced by a choice exercised by the females. These, whether *dominula*, *medionigra*, or *bimacula*, prefer to mate with either of the other forms rather than with their own. The sexes are in approximate equality, but while the males can mate many times the females do so once only. Consequently many males never pair. Such preferential mating will therefore favour *medionigra* males when the form is rare, and so tend to maintain the mutant gene. This, however, can be one only of the agencies responsible for its occurrence, and the changes in frequency to which it is subject, in this colony [3, 4].

Although extreme fluctuations in numbers are not likely to be responsible for the special characteristics of the Meadow Brown in Scilly, they are of great evolutionary importance. Indeed, I believe that plants and animals are far more subject to them than is generally appreciated; also that many populations generate such fluctuations autonomously, as it were. Natural environments are never constant, and when they favour a species its numbers increase and forms survive which would not normally do so. These are eliminated, and the numbers reduced, when the conditions become more rigorous again. Thus a numerical expansion prepares the way for a subsequent contraction. But the total effect is greatly to accelerate the speed of evolution; for the period of excessive variability, necessarily associated with it, allows new genic recombinations to become established, a process which would require a great length of time in a stable population. Any of them which may interact advantageously will be especially favoured when selection later becomes more severe. An example will make this clear.

A restricted colony of the Marsh Fritillary butterfly, *Euphydryas aurinia*, in Cumberland had remained remarkably constant in appearance while its numbers diminished from abundance to scarcity, from 1897 to 1912. For the next seven years the insects were rare, but from 1920 to 1925 an extraordinary increase took place; by the latter year they could be seen in thousands. From 1926 onwards the population remained at this level. Variation became very pronounced during this rapid numerical expansion. Hardly two specimens were alike, and many of the more abnormal were deformed or even unable to fly. When, however, the numbers became stabilized at a high level, from 1926 onwards, variability declined, so that the specimens assumed once more a relatively constant form; this, however, differed from that which had characterized the colony before the outburst of variability [5].

In most of the instances so far described, it is not known what advantages and disadvantages the various forms confer, nor what are the selecting agents. That information has, however, been obtained more or less fully in some other species.

One effective type of adjustment to changing conditions is found in the heterostyle-homostyle mechanism of certain plants such as the primrose, *Primula vulgaris*. These are typically heterostyled: that is to say, the flowers on each plant belong to one of two alternative types, so arranged as to promote cross-pollination between them. Since primroses of one or the other form occur together indiscriminately, and in approximate equality in most populations, the situation is one which promotes outbreeding with consequent opportunities for genetic variability. It is controlled by a mechanism involving constant back-crossing, with segregation in a 1 : 1 ratio. Plants of one type, the thrum (with high anthers and short pistil), are heterozygotes, and those of the other, the pin (with low anthers and long pistil), are recessives. Even when the relatively uncommon self-fertilizations, or crosses between similar phases, occur, few seeds are set; this incompatibility is controlled by the same locus as that responsible for the pin-thrum distinction. However, another allelomorph, or perhaps 'super-gene', brings the anthers and style to the same height and annuls the incompatibility just mentioned. Consequently both the morphological and physiological barriers to inbreeding are removed in the resulting 'homostyle' plants. After a few generations, these therefore become approximately homozygous, with resulting genetic fixation. Thus such species can pass from outbreeding with great variability to any degree of inbreeding, depending upon the proportion of homostyles carried by the population; this is a very refined evolutionary adjustment to different environments. It is one now being exploited by the primrose in Somerset; homostyles are spreading until they constitute a considerable proportion of the plants in part of that county.

The basis of natural selection has been analysed more fully in other species. The land snail, *Cepaea nemoralis*, is polymorphic for colour-pattern, i.e. various forms differing in appearance coexist in the same population in such proportions that even the less frequent among them are too common to be maintained merely by the rare process of recurrent mutation. These differences are genetically controlled. Pink shells are dominant to yellow, and brown are dominant (or epistatic) to pink; the absence of bands is dominant to their presence.

A. J. Cain and P. M. Sheppard [6] have studied this situation in many localities, and in the majority of them birds are the chief predators: especially the Song Thrush, *Turdus ericetorum*, a species which breaks the shells of its victims on convenient stones or 'thrush anvils'. Yellow shells are the commonest on green backgrounds, and banded on variegated ones. On such a uniform and brown background as that provided by a beech wood, brown unbanded shells are much the most abundant. It is found that inappropriate shell-types appear more often among the snails destroyed by thrushes than those better suited to the environment, as can be seen by their remains at the anvils. Moreover, in two open deciduous woods studied in detail, the proportion of the yellow form killed by thrushes declined from mid-April to mid-May, as the areas became greener. By marking large numbers of living snails, it was shown that this change was not due to the birds shifting their feeding grounds or to a decrease in the yellows among the population as a whole. It was, in fact, the result of visual selection by predators, affecting the frequency of certain genes in the snail population. As with the Meadow Brown in Scilly, it has in the past been claimed that 'genetic drift' accounts for the differences in proportion between the phases of this snail from one locality to another, a conclusion now clearly refuted.

The most striking instance of evolutionary response to changed conditions is provided by the industrial melanism of moths. During the last hundred years about seventy species have become black, or very dark, in manufacturing districts in Britain, where over 95 per cent of the population is sometimes affected. A similar occurrence has been observed in some other countries. These blackish forms are nearly always controlled by single genes, which are dominant or semi-dominant in effect. The change is due primarily to smoke pollution from factories and railways throughout such areas, and extending far beyond them carried by prevailing winds. The pollution not only blackens tree-trunks and rocks, but prevents the growth of lichens which normally make such surfaces paler than they otherwise would be.

The species are all such as sit fully exposed, protected by their cryptic coloration. H. B. D. Kettlewell [7], working on the Peppered Moth, *Biston betularia*, has shown that predators eliminate more of the black than of the pale form in unpolluted woods, while the converse is true in industrial regions. The species concerned are birds; Song Thrushes, *Turdus ericetorum*, Flycatchers, *Muscicapa striata*, and others, which feed upon the moths when resting upon tree-trunks and boughs, picking out the more conspicuous specimens.

Kettlewell's large-scale experimental studies have shown not only that birds attack moths when resting upon trees, but that they do so in great numbers. No animals are collected so much as butterflies and moths, nor observed so assiduously as birds, yet entomologists and ornithologists have until now been unaware of such predation and have indeed for generations strongly denied it. Furthermore, the Meadow Brown is one of the commonest British butterflies, yet the remarkable sexual difference in its spotting was discovered only in 1947, while the fact that thrushes prey selectively upon snails was not fully established until 1950 for banding and 1951 for colour. Indeed, those naturalists interested in biological problems, rather than in groups of animals or plants, can make striking discoveries in regard to the most familiar species; while ecological and genetic methods can now be used to demonstrate the occurrence of evolution in wild populations and to analyse it experimentally.

REFERENCES

[1] FISHER, R. A. *Proc. roy. Soc. Edinb.*, 50, 204, 1930.

[2] DOWDESWELL, W. H. and FORD, E. B. *Symp. Soc. exp. Biol.*, 7, 254, 1953.

[3] FISHER, R. A. and FORD, E. B. *Heredity*, 1, 143, 1947.

[4] SHEPPARD, P. M. *Ibid.*, 5, 349, 1951.

[5] FORD, E. B. 'Mendelism and Evolution' (5th edition). Methuen and Company Limited, London. 1949.

[6] CAIN, A. J. and SHEPPARD, P. M. *Genetics*, 39, 89, 1954.

[7] KETTLEWELL, H. B. D. *Heredity*, 9, 323, 1955.

Electron microscopy: its scope and limitations

V. E. COSSLETT

Recent improvements in the methods of preparing material for electron microscopy, and especially in the technique of cutting sections, have made the method applicable in almost the whole field of classical microscopy, apart from the observation of living material. This authoritative article reviews the progress made in the study of the fine structure of both biological and inorganic material, the scope and limitations of the method, and the principal difficulties that are encountered in the unambiguous interpretation of results.

The first reports of success with an electron microscope appeared early in 1932 [1]. The types of electron lenses, electrostatic and magnetic, which had been developed primarily for the cathode-ray tube had been adapted to form magnified images. The electrostatic lens has carried the day in the oscillograph, but the magnetic type has come into almost general use for microscopy. Today, within less than twenty-five years, the electron microscope has made for itself a place of some importance among research tools for investigating the microstructure of matter. Ernst Ruska, who built the first magnetic electron microscope as his *Diplomarbeit* in the *Technische Hochschule* of Charlottenburg, later designed a production model for Siemens and Halske, and has continued to direct their electron optics section ever since. He still leads in the construction of electron microscopes of high performance. The new Siemens Elmiskop has a resolving power of 10 Å or better. All the major industrial countries now manufacture electron microscopes, Japan in the largest numbers, but the only serious rival to the Elmiskop is the Metropolitan-Vickers EM6, the prototype of which was shown at the 1956 Exhibition of the Physical Society in London.

What can today be expected of electron microscopy is best seen by considering the range of dimensions of natural structures (figure 1), from the limit of resolution with the unaided eye (0·25–0·1 mm) to the size of an atom (2·5–1 Å). The limit of optical microscopy, using ultra-violet light, lies just half-way down this range: the

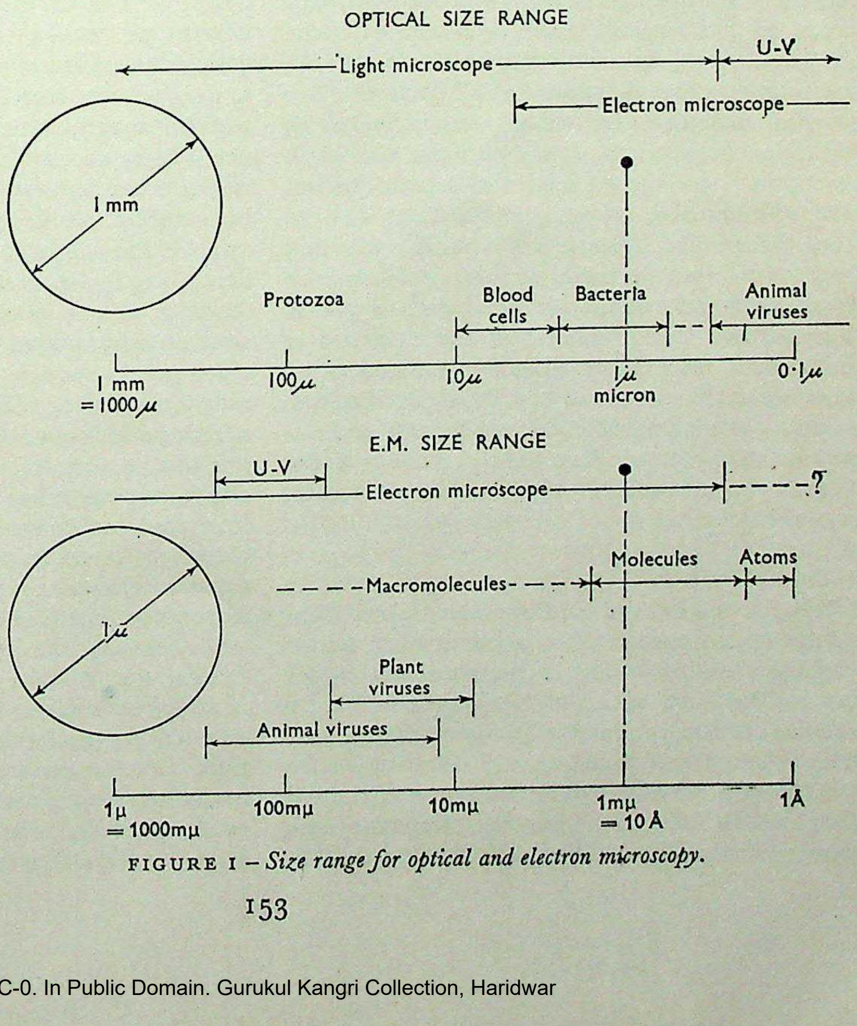

OPTICAL SIZE RANGE
Light microscope
U-V
Electron microscope
1 mm
Protozoa
Blood cells
Bacteria
Animal viruses
1 mm = 1000μ
100μ
10μ
1μ micron
0·1μ
E.M. SIZE RANGE
U-V
Electron microscope
?
Molecules
Atoms
Macromolecules
1μ
Plant viruses
Animal viruses
1μ = 1000mμ
100mμ
10mμ
1mμ = 10 Å
1Å

FIGURE 1 – *Size range for optical and electron microscopy.*

electron microscope may be expected ultimately to attain a resolving power of atomic order, so that it should double the range of microscopical investigation. In rough terms, the use of a simple lens increased our optical range tenfold, the combination of two lenses to form a compound microscope added another order of magnitude, and the improvements of the past century in optical microscopy added yet another. The first electron microscope gave a similar step forward and the refinements of the past two decades still another tenfold advance. Research now in progress in several laboratories, primarily in Germany and Great Britain, offers reasonable prospects of carrying the limit from 10 Å down to 1 Å; the present limit in experimental microscopes lies around 5–6 Å.

The value of such a resolving power depends, of course, on what there is to be seen beyond the normal optical limit. In biology it was already clear that there existed a whole range of animal and plant viruses, as well as the macromolecular components of larger organisms, which would repay detailed investigation. In fact, electron microscopy has revealed a new world of microstructures in all tissues and even in viruses themselves. In the inorganic world, dusts and powders, precipitates and colloidal suspensions, were obvious subjects, but it was not at all clear whether any fine structure was to be found in metals in the range between the etch patterns visible in the optical microscope and the atomic lattice. Here the electron microscope has been able to show the reality of steps and spirals and other features of crystal growth, as well as of the slip lines and bands which are produced in plastic deformation. The postulate of the existence of dislocations, in explanation of these and other phenomena, has set a new goal for electron microscopists—to make visible the lattice itself and imperfections in it (see figure 14). This goal has already been attained with certain molecular crystals.

THE INSTRUMENT

The general lines of the instrument follow those of the optical microscope: a condensing system projects illumination on to the specimen, which lies in the focal plane of the objective, and a subsequent lens provides additional enlargement. The differences of principle and construction follow from the essentially different nature of the two forms of illumination. Light, an electromagnetic wave motion, is focused by the fields within certain solid or liquid aggregations of particles (transparent media). Electrons, a particulate radiation, are focused by electromagnetic fields of appropriate distribution, and are scattered by other particles. This latter phenomenon is a disadvantage in that it requires the electron path to be in high vacuum, but on the other hand it is the primary source of image contrast: various parts of the specimen will appear light or dark, depending on differential scattering of electrons. Micrographs of graded density are thus obtained, not mere silhouettes, provided that the specimen is below a certain thickness: this is of the order of the wavelength of violet light (3000 Å).

The wave nature of the electron need be invoked only when a quantitative treatment of image formation, and in particular of resolving power, is required. Apart from lens aberrations, which are severe, the ultimate limit to resolution is set by the equivalent wavelength of the illuminating electron beam, which depends inversely on the square root of the accelerating voltage. A high voltage is thus needed, and for the range most in use (50–10 kV) the equivalent wavelength varies from 0·054 to 0·037 Å. A resolving power several orders beyond that of the optical microscope would therefore be expected, even with electron lenses which correspond in crudity to the early uncorrected lenses of glass optics. The working magnification of an electron microscope needs to be correspondingly higher. An image in which points separated by 10 Å are resolved has to be enlarged until they are more than 0·1 mm apart if the eye is to appreciate all the recorded detail, i.e. by at least 100 000 times. For ease of viewing, and to allow for better resolution than 10 Å, another power of ten is desirable, and many micrographs are now reproduced at a useful magnification of the order of one million times. Such a high value is not attained directly in the electron microscope, as it would require an electron source of higher power than any yet available, unless an image intensifier were to be used for viewing the picture. Direct magnifications up to 100 000 times or more are provided (in the Elmiskop, up to 160 000 times) and a viewing telescope is used when focusing the image.

The construction of an electron microscope of modern design is shown schematically in figure 2, with ray paths for medium high magnification. The beam from a triode electron gun is projected through the anode diaphragm A, at earth potential, into a two-stage condenser, C_1 C_2, which throws a beam, the intensity and

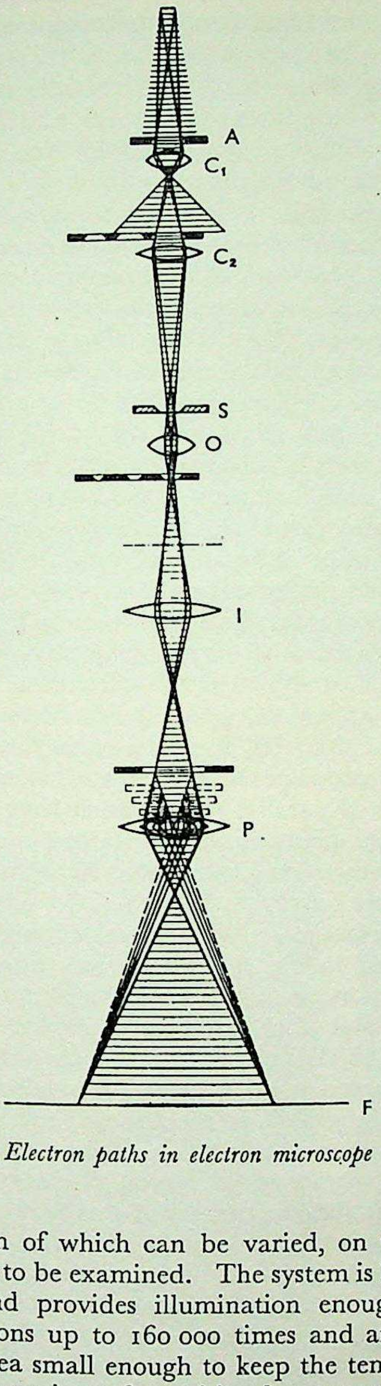


FIGURE 2 – *Electron paths in electron microscope of high power.*

cross-section of which can be varied, on to the specimen S to be examined. The system is highly efficient and provides illumination enough for magnifications up to 160 000 times and an illuminated area small enough to keep the temperature of the specimen from rising by more than a few tens of degrees. The imaging system consists of the high-power objective O, followed by an intermediate lens I and a final projector lens P; the maximum stage magnifications are of the order of × 200, × 10, and × 100 respectively. Electron diffraction may be practised by focusing on the back focal plane of the objective instead of on the specimen. For photographing, the fine-grained fluorescent screen F on which the image is viewed can be raised; plates are preferred to film for high-resolution work. The body of the instrument is continuously evacuated with high-speed pumps, and specimens are introduced through an air-lock. The high-voltage supply and the current for the windings which excite the magnetic lenses must be stabilized to the order of 1 part in 10^5 in order to provide a monochromatic beam; this is normally done in a separate unit in order to keep disturbing fields at a distance from the microscope. The lenses consist of windings within an iron casing, the field being concentrated on the axis between conical polepieces of small bore; the excitation may be as high as 5000 amp. turns and the focal length as small as 1 mm. Of the various aberrations, only the astigmatism arising from lack of rotational symmetry of the field can at present be corrected, by means of trimming fields generated by a 'stigmator' fitted into the objective; these can be varied in strength and azimuth while the effect on the image is observed. It is also most important for all the lenses to be centred on the same axis, and each is provided with transverse shift controls for this adjustment; the condenser system may also be tilted about the specimen position.

APPLICATIONS IN BIOLOGY AND MEDICINE

The first and obvious use of the electron microscope in biology was for the sizing of living particles too small to be measured in the optical microscope: bacteria, rickettsia, animal and plant viruses, and bacteriophages. A great deal has been done and continues to be done in this field. Studies have also been made of the external morphology of micro-organisms, such as the flagella of bacteria and spirochaetes, and of their detailed structure in so far as it can be revealed through degradation by thermal and mechanical treatment, enzymatic action, and selective extraction. Much has been learnt in this way about the bacterial cell wall, the mode of action of bacteriophage, and the effect on the morphology of bacteria of the medium on which they are grown, for instance. But the whole use of the electron microscope in biology has been revolutionized by the recent development of the technique of cutting thin sections, which has at last opened up the study of bulk tissues to electron microscopy.

As developed for optical microscopy the microtome could cut sections as thin as 1 micron but rarely thinner. Since doubts were expressed, on theoretical grounds, about the possibility of cutting very much thinner sections by the classical methods, attempts were at first made, especially in the United States, to cut at extremely high speeds, for instance by fitting the knife or specimen in the edge of a wheel or even of a centrifuge disc. The aim was to minimize the effect of the shock wave ahead of the cutting edge. Little came of these experiments, and it was not long before L. H. Bretschneider in Delft, and D. C. Pease and R. F. Baker in the United States, showed that microtomes of conventional design could be made to cut sections at least down to 0·1 micron thick by refinement of the advance mechanism [2].

The resolution obtained in the image of a section depends upon its thickness, because of the confusion produced by inelastically scattered electrons [3]. The resolution is about one-tenth the thickness, so that specimens as thin as 100 Å must be cut if full advantage is to be taken of an instrumental resolving power of 10 Å. Attention has therefore been directed to special microtome systems, designed to give greater thermal and mechanical stability and improved regularity of sectioning down to 100 Å and below. The types which have found most favour are those which employ controlled thermal expansion for advancing the specimen. When sections as thin as a tenth of the wavelength of light are being cut, it is important to prevent the specimen block brushing against the knife, to which the cut section is adhering, on the way back to its undisplaced position. Such a single-pass action is attained in a variety of ways: by rotating the end of the rod carrying the specimen (F. S. Sjöstrand [4], A. J. Hodge, H. E. Huxley, and D. Spiro [5]), by guiding it through a gate by a cam system (K. R. Porter and J. Blum [6]), or, most neatly, by making the rod of nickel and utilizing magnetostriction (H. B. Haanstra [7]). The last named has produced the thinnest sections (60 Å) and the best evidence of repetivity. For ultra-microtomy, as it has come to be called, a very hard embedding material is required, and the usual method is to embed in monomeric methacrylate, which is then allowed to polymerize. A lozenge of cut glass is found to give the best cutting edge; but it soon deteriorates, and attention has returned to refinements in sharpening the normal type of microtome knife or safety-razor blades. A full account of present technique is given in a review by Sjöstrand [8].

The wealth of information revealed by these new methods can be compared, in fascination as well as in quantity, only with that which came from the first microscopical explorations of Hooke and van Leeuwenhoek. Every type of tissue examined has been found to contain a great complexity of membranes, canals, and particles, ranging through the macromolecular domain down to the limit of observation. The vital processes of the cell are shown to depend on a most intricate microstructure, which is rapidly being mapped. It is possible here to indicate only some of the main features which have emerged.

The cytoplasm of many animal cells—kidney, liver, pancreas, nerve, and so on—contains a ramifying system of double membranes, to which particles often appear to adhere (figure 3). G. E. Palade and Porter [9] suggest that this is a fundamental feature of all tissue and name it the 'endoplasmic reticulum'; it appears also in discrete bodies, such as the mitochondria, which occur in the cytoplasm. Sjöstrand, however, already distinguishes at least three forms of 'cytomembranes'. Detailed serial sectioning is now needed to show what may be true membranes and what may in fact be canals. Work is actively proceeding on the architecture of specialized regions of the cell such as the so-called Golgi apparatus, which is now shown as a complex of vacuoles, membranes, and particles. Of the greatest interest are the extraordinarily regular arrays of parallel plates which have been found in chloroplasts and in the retinal rods. Electron microscopy has also revealed fine structural detail in nerve cells [41].

In comparison with the richness of detail discovered in the cytoplasm, very little has so far come out of studies of the cell nucleus and in particular of chromosome structure. It has been conclusively proved, as had long been suspected, that small pores exist in the nuclear wall, permitting passage of the contents to the cytoplasm and *vice versa*. But the nucleus itself has seemed singularly devoid of structure. It is possible that this is indeed the normal condition and that microstructure exists only at certain periods of the cell cycle. It is more probable, however, that structure is destroyed during the fixation and embedding processes. Here, as in many other biological problems, a co-ordinated attack with optical and electron microscopical techniques is required. In a recent comparative study, I. R. Gibbons and J. R. G. Bradfield [10] have found that the methods of fixation with osmium tetroxide, normally so successful for the cytoplasm, show hardly any differentiation between chromosomes and nucleus (figure 6) in conditions where ultraviolet microscopy shows them to be highly defined. Formalin fixation gives rather better contrast between chromatin and nuclear sap. Much more

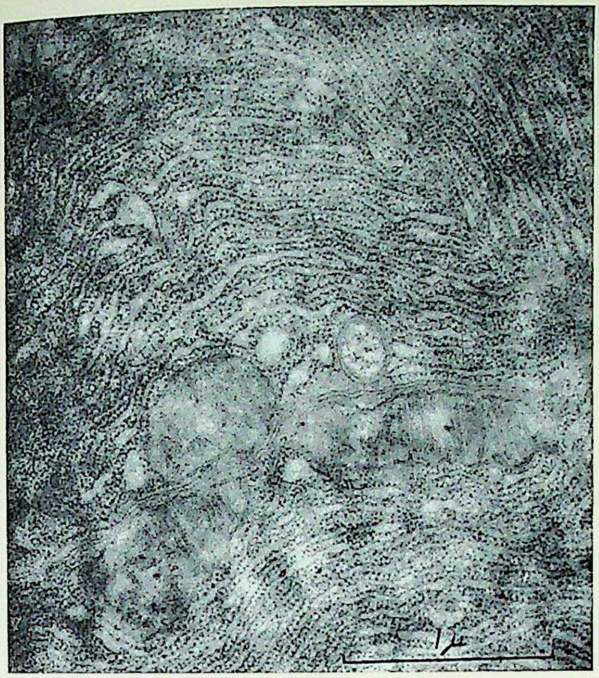


FIGURE 3 – *Section of pancreas, showing cytoplasmic membranes and adhering particles. (By courtesy of Professor F. S. Sjöstrand and 'Experimental Cell Research'.)*

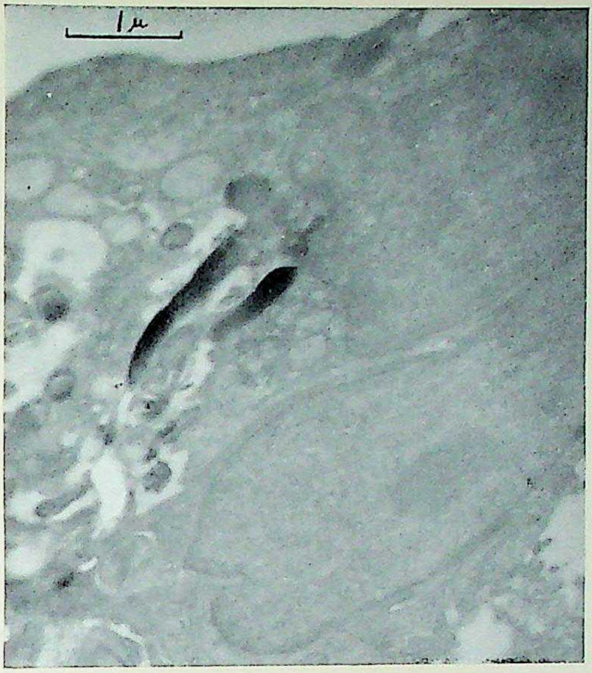
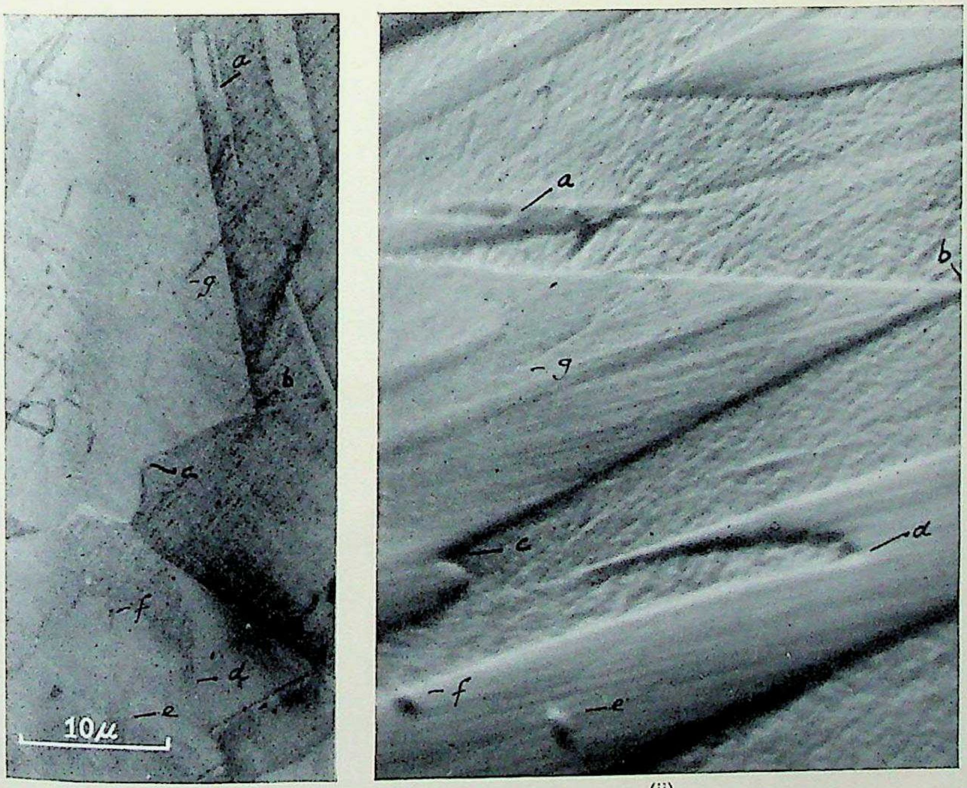


FIGURE 4 – *Tubercle bacilli, bovine strain. Thin section of lung of infected mouse, showing dense filamentous bacteria in vacuolized cytoplasm. (Dr E. M. Brieger and Miss A. M. Glauert, Strangeways Laboratory, Cambridge.)*



(i) (ii)

FIGURE 5 – *Surface of 60-40 brass, lightly etched.* (i) *Optical micrograph.* (ii) *Reflection electron micrograph at a foreshortening of 1 in 7. Corresponding features in the two prints are labelled a, b, c, etc. (Dr D. Jones, Cavendish Laboratory, Cambridge.)*

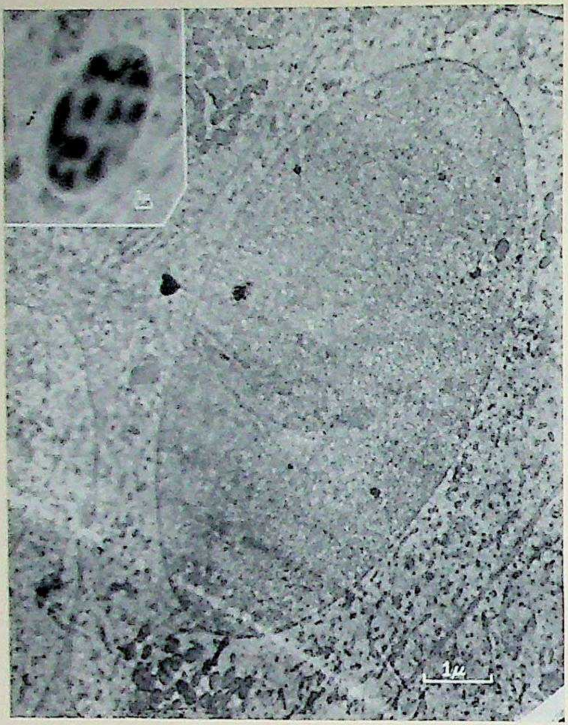


FIGURE 6 – *Cell nucleus, in prophase of meiosis, from testes of* Locusta migratoria. *Transverse bands are knife-marks.* Inset: *Ultra-violet micrograph of same nucleus; succeeding section.* (*Mrs A. Cosslett and Mr I. R. Gibbons, Cavendish Laboratory.*)

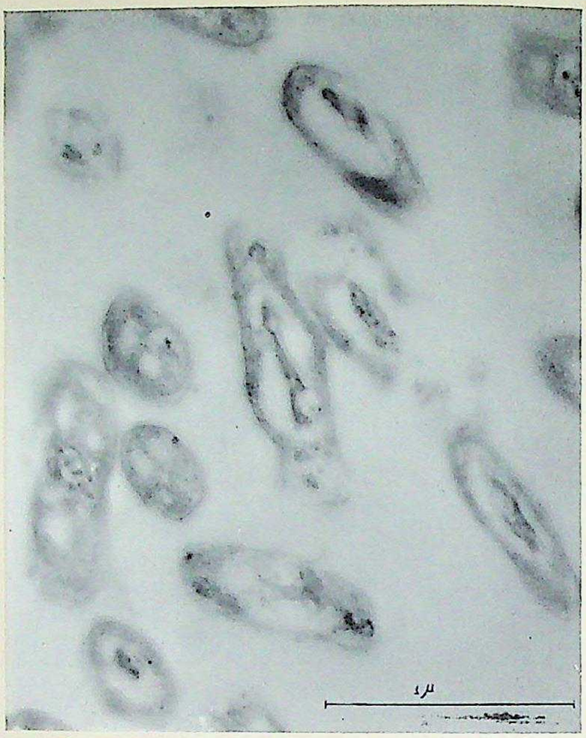


FIGURE 7 – *Tubercle bacilli, avian strain. Thin section of artificial culture after 24 hours' growth, showing complex internal structure.* (*Dr E. M. Brieger and Miss A. M. Glauert, Strangeways Laboratory, Cambridge.*)

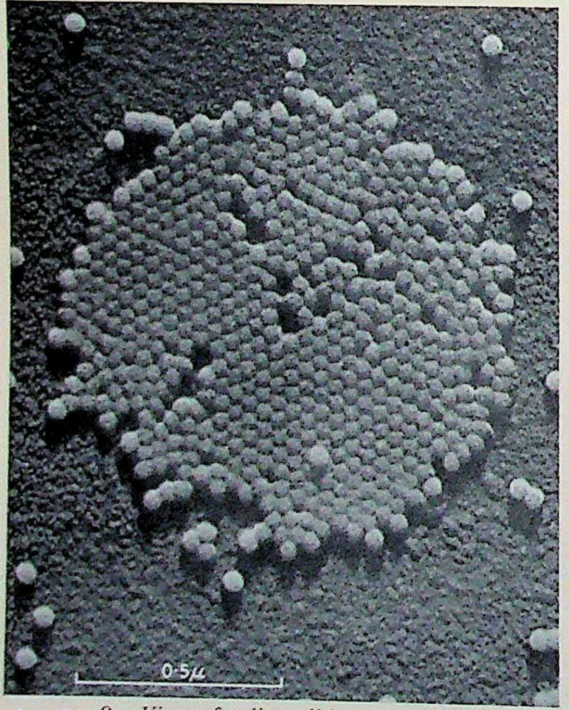


FIGURE 8 – *Virus of poliomyelitis, metal shadowed.* (*Dr R. C. Williams, Virus Laboratory, University of California.*)

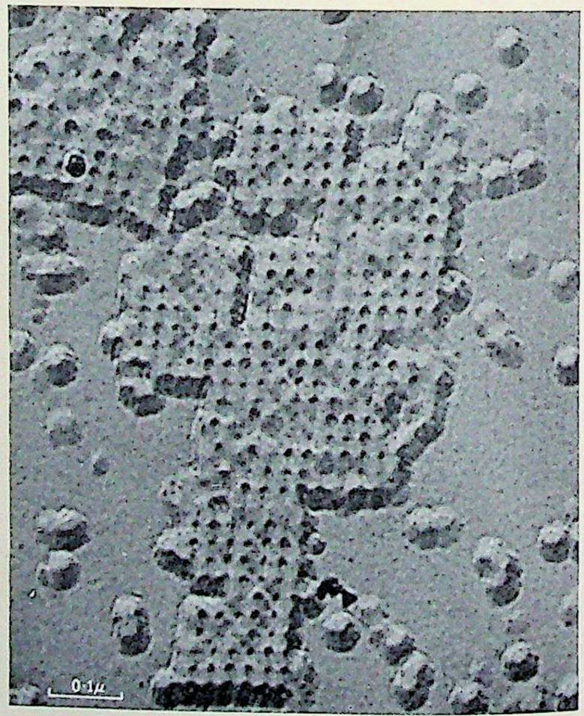


FIGURE 9 – *Turnip yellow virus. Isolated particles are polyhedral, not spherical. Carbon replica.* (*Dr R. Markham, A.R.C. Virus Research Unit, Cambridge, and Mr R. W. Horne, Cavendish Laboratory.*)

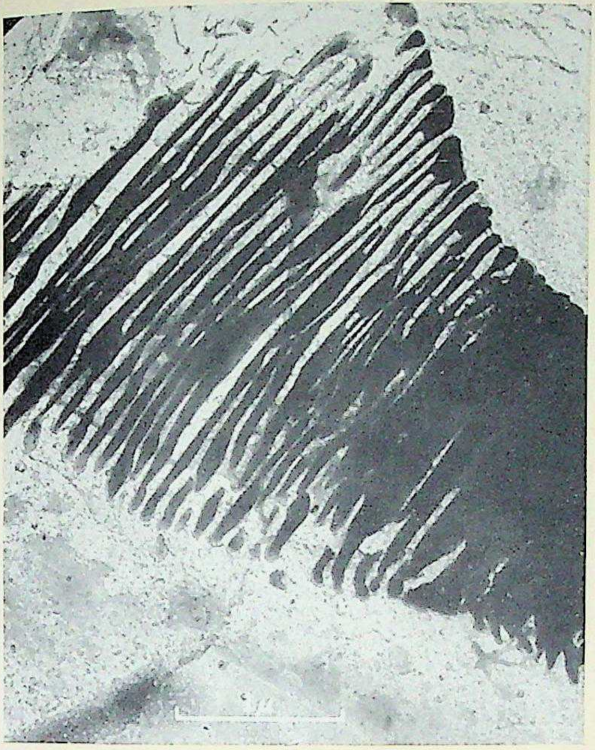


FIGURE 10 – *Laths of cementite, from pearlite. Extraction replica.* (*Dr J. Nutting and Mr E. Smith, Department of Metallurgy, Cambridge.*)

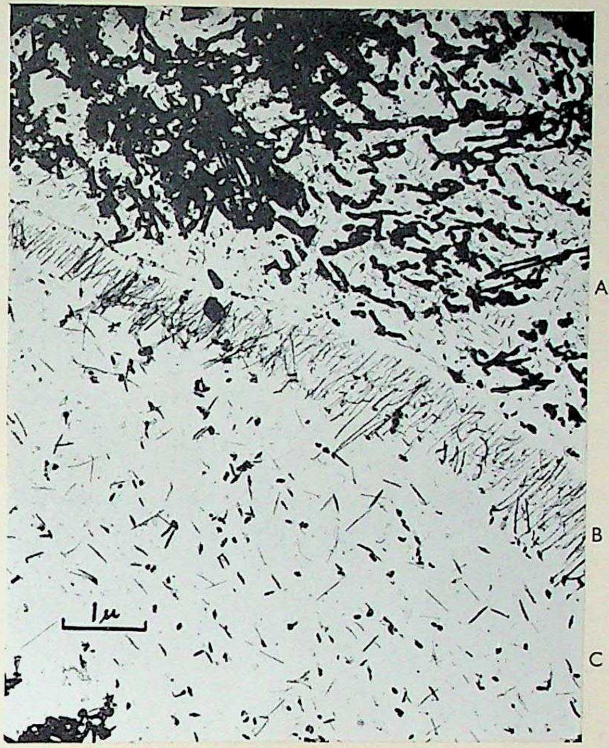


FIGURE 11 – *Precipitates from a chromium-molybdenum steel. A is* Fe_3C, *B is* Mo_2C, *and C is* Cr_7C_3. *Extraction replica.* (*Dr J. Nutting and Mr E. Smith, Department of Metallurgy, Cambridge.*)

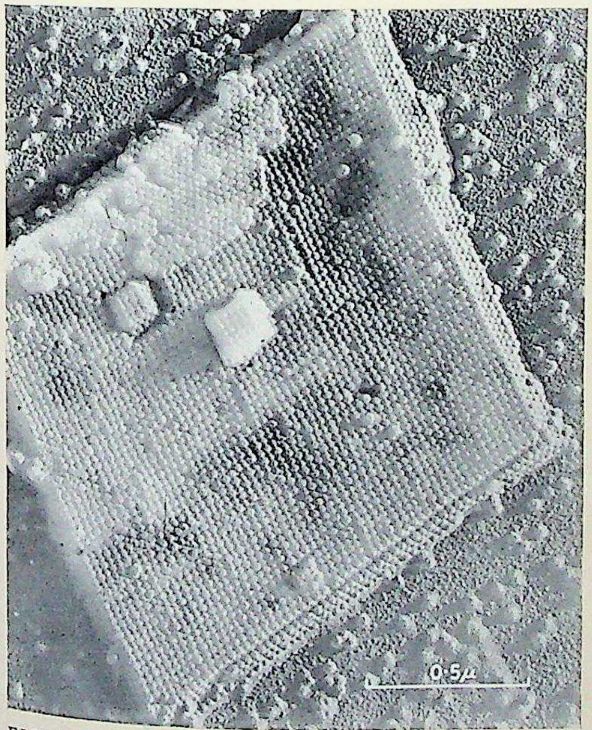


FIGURE 12 – *Tobacco necrosis virus crystal; carbon replica of metal-shadowed preparation.* (*Dr R. W. G. Wyckoff and Dr L. W. Labaw, National Institutes of Health, Bethesda, Maryland.*)

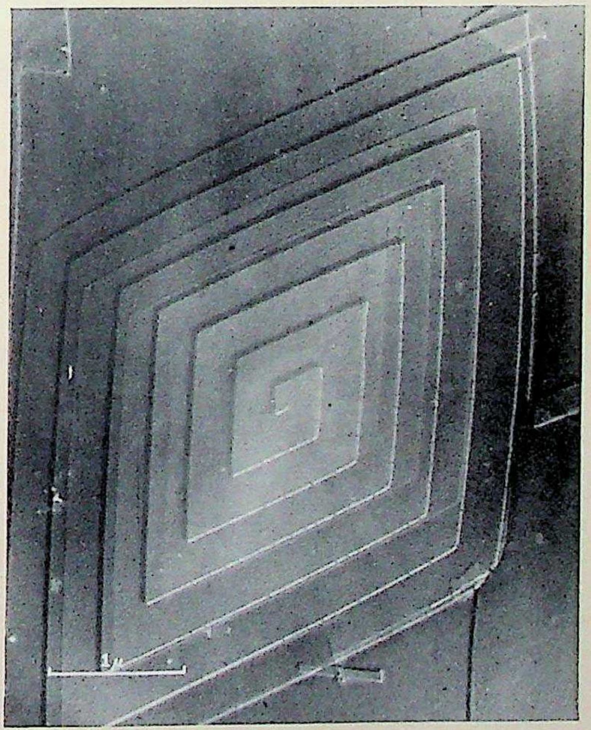


FIGURE 13 – *Single crystal of n-hectane, showing spiral growth front arising from a single dislocation centre; shadowed with palladium.* (*By courtesy of Dr I. M. Dawson, University of Glasgow.*) (Proc. roy. Soc. A., 214, 72, 1952.)

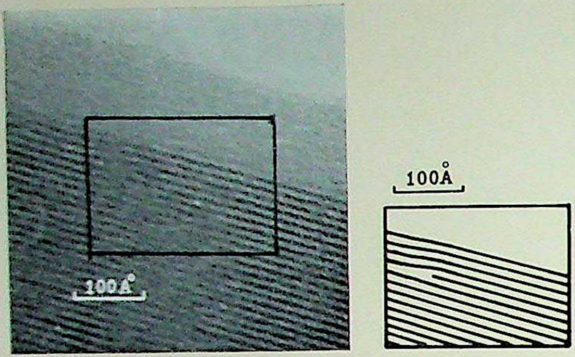


FIGURE 14 – *Platinum phthalocyanine, showing edge dislocation; 20$\bar{1}$ planes, spacing* 11·97 Å. (*Dr J. W. Menter, Tube Investments Research Laboratories, Hinxton Hall, Cambridge.*)

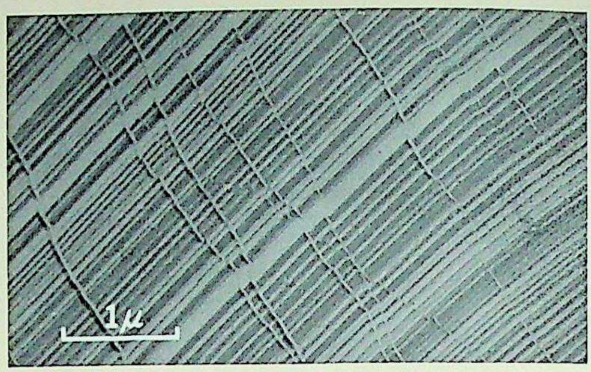


FIGURE 15 – *Slip steps in heavily deformed α-brass. Silicon monoxide replica.* (*Dr H. Wilsdorf, National Physical Laboratory, Pretoria, South Africa.*)

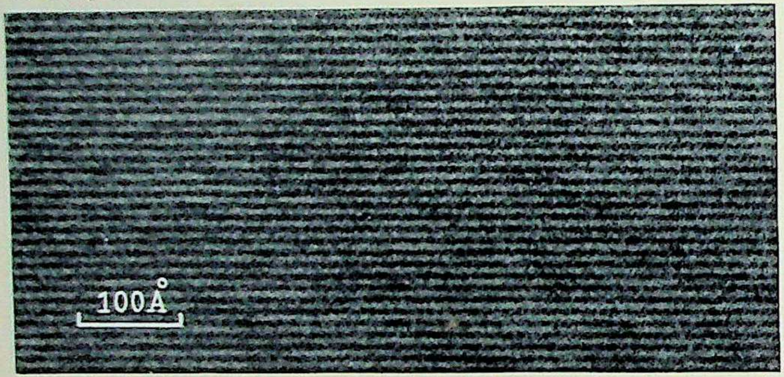


FIGURE 16 – *Copper phthalocyanine, showing 20$\bar{1}$ planes, of spacing* 10·30 Å. (*Dr J. W. Menter, Tube Investments Research Laboratories, Hinxton Hall, Cambridge.*)

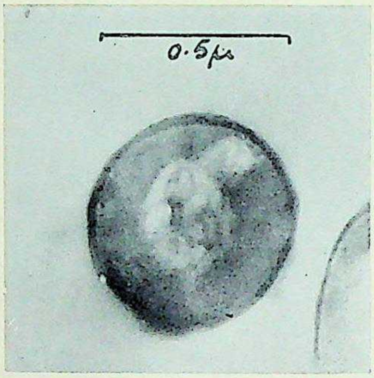


FIGURE 17 – *Staphyloccus aureus in thin section.* (*Dr J. R. G. Bradfield, Cavendish Laboratory, Cambridge.*)

definite structure is found in the heads of spermatozoa, which are known from their birefringence to contain a degree of orientation.

This example stresses the present need in electron microscopy for that same detailed and painstaking investigation of methods of fixation, embedding, and staining as was undertaken in the classical work of Hardy and others in optical microscopy at the end of the last century. We need to know much more about the effect of reagents on the cell at a much lower level of structure than those workers were concerned with, and indeed right down to the molecular organization. Artefacts of drying, on the other hand, are less severe than was at first anticipated. The new field of micro-cytology calls for its own micro-histological techniques, and it is to be expected that these will differ greatly from the established macro-methods. In order to make many structures visible in light a great deal of precipitation and aggregation of cell contents must undoubtedly be produced. For instance, G. Rosza and R. W. G. Wyckoff [11] have shown that some of the fibrous appearances classically associated with mitosis are hardly to be seen at all in electron micrographs; their reality at the molecular level is shown by their birefringence in the living dividing cell. The preservation of macromolecular structure is one of the main tasks in the perfection of the technique of preparing specimens for electron microscopy. In solving it, what has been learned from the development of classical microscopy is likely to be more than repaid in the refining and elucidation of structures which optical methods necessarily can show only crudely, even if they do not distort them or destroy them altogether. An attempt at such a refinement of technique has been made in Sjöstrand's laboratory [12] in respect of the alkaline phosphatase long known to exist in the brush border of the intestinal epithelium.

In its medical applications also, electron microscopy now needs more critical and fundamental investigations. Studies of pathological conditions have been pushed ahead before we know very much of the microstructure of the normal cell or of infective agents in isolation. For instance, early claims of the existence of virus-like bodies in cancerous tissues have been followed by the demonstration that in many cases most if not all of these particles occur in the normal healthy cell: the necessary painstaking comparative work is now being undertaken in the leading cancer research centres. In the case of tuberculosis the situation is rather farther advanced, in that we now have evidence that the appearance of the bacillus in infected tissues is very different from what it is in cultures (figures 4 and 7). Thin-sectioning technique has now made possible the systematic investigation of the infective agent, whether virus or bacterial, in the host. Some work has been done with leprosy as well as with tuberculosis, but very much more with plant and animal viruses. The location of the infection, whether in nucleus or cytoplasm, can be found, and the stages in the development of the agent followed. In most cases these are proving to be more complicated than expected, especially with plant viruses. Studies of the effect of therapeutic agents, such as antibiotics, have been reported.

Investigation of the internal structure of isolated bacteria and viruses and other micro-organisms has also followed upon the development of ultramicrotomy. Some account of the structure of spermatozoa was given in a recent issue of this journal by Lord Rothschild [13]. Bacteria, far from being just sacs full of assorted enzymes, are found to have quite complex internal structures. Cocci show a central nucleus surrounded by cytoplasm exactly as in larger cells (figure 17); silver staining proves the nucleic acid to be located in the central region, which in unstained sections contains well defined threads that might be the genetic material (Bradfield [14]). Rod bacteria, however, show an extended nuclear region, the ramification of which depends on the age of the culture. In aureomycin-treated cells E. Kellenberger and A. Ryter [15] find more nearly spherical vacuoles containing fine threads, similar to the nuclei of cocci, but they are doubtful of identifying them as nuclei and chromosomes. It is now well established, however, that the bacterial nucleus is usually a region of lower density than the cytoplasm, as first indicated by C. F. Robinow [16]. Many species regularly contain dense round bodies, which have been variously claimed as mitochondria, nuclei, and spores. A careful study by A. M. Glauert and E. M. Brieger [17], in which the same cells were photographed in both the electron microscope and the optical microscope, after application of a number of standard staining processes, showed that the bodies failed to respond to the normal tests for either nuclei or mitochondria. They contain metaphosphates and probably ribonucleoprotein, but not deoxyribonucleoprotein, and are probably to be classed with the metachromatic volutin granules observed by other workers.

Many of the larger animal viruses have been shown to have a degree of organization since the original demonstration by I. M. Dawson and A. S. McFarlane [18] of a central dense region in vaccinia virus, probably to be identified as a nucleus. The smaller animal viruses, such as that of polio (figure 8), and the spherical plant viruses, have not yet been shown to have structure and may be single macromolecules, although the existence of two forms of turnip yellow virus, one containing much more nucleic acid than the other, would indicate that the latter substance occupies a definite position. In tobacco mosaic virus, beautiful work by G. Schramm and his school [19] has shown conclusively that the nucleic acid fibres form the core of the rod, on to which 'beads' of protein are threaded. R. C. Williams [20] has shown that the rods are hexagonal in cross-section but found free-lying nucleic acid fibres of about half the diameter of those found by Schramm (34 Å). The availability of microscopes of much higher resolution than those with which these investigations were made will allow still finer details of virus structure to be demonstrated. R. Markham and R. W. Horne [21] have, indeed, already shown that turnip yellow virus particles are not spheres, as they appear to be at poorer resolution, but have a definite crystallographic form which agrees with their macroscopic habit in crystal formation (figure 9).

These virus problems apart, the main task in biological applications of the electron microscope is the refinement of preparative methods. Very few specimens, including thin sections, show a resolution better than 20–30 Å. If smaller macromolecular detail is to be made visible, as the instrumental resolving power would allow, we need careful investigation of the factors limiting present methods, in the hope that means of preserving finer structures will be found.

METALLURGICAL APPLICATIONS

Since all metal specimens of interest, except very thin films, are impenetrable to the electron beam, replica techniques were early devised for studying surface structure. Plastic films, such as nitrocellulose and Formvar, have been much favoured, but many other materials have also found use, especially evaporated films of silica, silicon monoxide, and some metals. A great deal of useful information has been obtained in this way about the detailed structure of fracture surfaces, grain boundaries, slip bands, and many other features which occur naturally, or after etching, on the surface of a wide variety of metals. Two recent developments have greatly extended the scope of the electron microscope in metallurgy, and indeed for surface studies generally: the discovery of a replica technique of much better inherent resolution than any hitherto known, and the perfection of reflection microscopy and other means of directly examining the surface of a solid specimen.

Most replica methods used until recently were limited, primarily by self-structure, to a resolution of the order of 200 Å; silicon monoxide gave rather better results. The carbon replica method devised by D. E. Bradley [22] appears not to suffer from this defect, at least down to a resolution of 10 Å. The carbon is evaporated from an arc and is deposited either directly on the specimen or on a thick primary replica in a plastic material. The carbon film, which is usually about 100 Å in thickness, is then floated off in a suitable solvent and mounted in the usual way for electron microscopy. The films are surprisingly strong and may be handled and examined in the electron beam without undue precautions; Bradley has successfully used films as thin as 25 Å. On account of its toughness the carbon film is coming into wide use as a specimen support, especially for thin sections, for which only the very minimum of extra scattering matter can be tolerated in high-resolution microscopy. The carbon film is also the basis of the extraction replica method due to J. Nutting and E. Smith [23], by which the arrangement of precipitated material in a surface may be preserved for study by electron microscopy and diffraction. After carbon has been deposited on the surface, the main body of the metal is removed by immersion in a suitable reagent. The carbon film floats free, bearing in it any insoluble precipitates that were in the metal surface. The material from a normalized and tempered chromium-molybdenum steel is shown in figure 11; electron diffraction identified the three components as carbides of iron, molybdenum, and chromium. The method is finding a wide variety of applications; figure 10 shows laths of cementite extracted from pearlite, the preferred orientation in which was then proved by electron diffraction.

The direct observation of surfaces by electron reflection was briefly investigated in 1939–40 by German workers, and was revived in Cambridge after the war [24]. The principle is shown in figure 18. The illuminating system of the electron microscope is tilted through an angle of some 10°, so that the beam falls on the specimen surface at an angle of the order of 1°. Scattered electrons (it is in no sense a specular reflection) pass into the aperture of the objective lens and form an image in the usual way, except for the foreshortening due to the inclination of the specimen. This angle is usually about 8°, so that the image is foreshortened in the ratio 1 : 7; the transverse and longitudinal magnifications differ in the same degree, so that angular relations are distorted. Comparison with a normal optical picture (figures 5(*a*) and (*b*)) shows that care is called for in interpreting the micrographs. Recently, however, excellent results have been obtained by C. Fert [25] at a foreshortening of only 1 : 2; resolution is even better than at a ratio of 1 : 7, but exposure times are longer.

The advantage of the reflection method is that it allows direct observation of a surface during treatment, which may be thermal, mechanical, or chemical. D. Jones [26] has obtained micrographs of a silver surface at temperatures up to 900° C. with a miniature furnace built into the specimen stage. A wide variety of surfaces has been investigated by J. W. Menter [27]: they include diamond, rayon, and other non-conductors, which give satisfactory images if first coated with an evaporated layer of silver. When the surface is rugged, or is difficult to replicate by the usual techniques, the reflection method is of value even when no treatment is desired. It has the disadvantage, however, of a relatively poor resolution, the best results being not better than 250 Å. The cause of this lies in the wide scatter of velocities in the 'reflected' electron beam, and little improvement is likely until an achromatic lens can be designed. Meanwhile the reflection method is finding many applications, especially in industrial laboratories.

A number of other techniques for surface investigation have been devised. D. McMullan [28] has revived and improved the scanning or flying-spot microscope, in which a fine electron spot is scanned across a surface, the scattered electrons giving a signal which is amplified and displayed on a synchronously operated cathode-ray tube. The

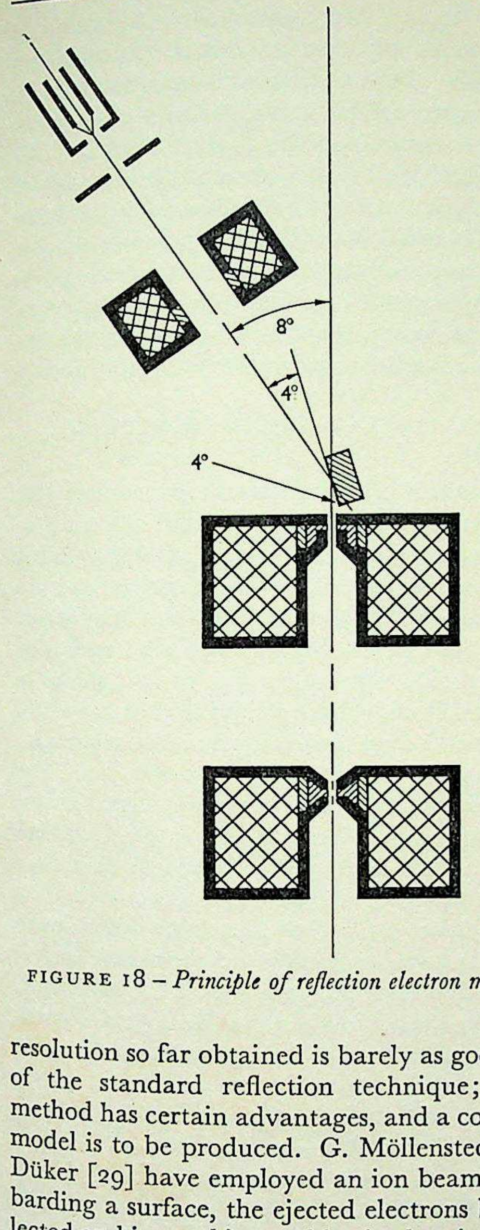


FIGURE 18 – *Principle of reflection electron microscopy.*

resolution so far obtained is barely as good as that of the standard reflection technique; but the method has certain advantages, and a commercial model is to be produced. G. Möllenstedt and H. Düker [29] have employed an ion beam for bombarding a surface, the ejected electrons being collected and imaged in an objective lens in the usual way. The micrographs so far shown have a resolution at least as good as that of the reflection method and a striking three-dimensional appearance, which may be due to etching of the surface under bombardment. Microscopes have also been constructed in which the cathode itself is the specimen, images being formed with the thermally emitted electrons. Interesting results have been shown of phase changes at high temperatures in iron, molybdenum, and other metals [30]. A commercial model of this emission electron microscope has now been produced by Philips of Eindhoven.

All these techniques are finding applications, and in this sense metallurgy is better served by electron microscopy than is biology. So far, however, almost all the work published has been on the fundamental chemistry and physics of the subject and has not yet been reflected in routine analytical or etching procedures. In an endeavour to ensure uniformity in basic methods, an important step in establishing routine techniques, the American Society for Testing Materials set up a sub-committee some years ago which has issued several reports on replica methods [31]. There is no doubt that in a few years the great deal of investigation going on in 'academic' metallurgy will begin to have an impact on the traditional processes of its technology, especially in connection with the newly developed alloys for special purposes.

APPLICATIONS IN SOLID-STATE PHYSICS

In addition to this type of metallurgical studies, the electron microscope is being increasingly used to investigate the ultra-microscopic physical processes which constitute or accompany crystal growth, plastic deformation, and so on. One of the first studies was of slip in metals. R. D. Heidenreich and W. Shockley, and A. F. Brown [32] were able to show that slip lines at a separation of the order of 1000 Å occurred within the macroscopic slip bands. More detailed work by D. Kuhlmann-Wilsdorf and H. Wilsdorf [33] with the SiO replica method has distinguished two types of slip. In pure metals such as aluminium, silver, and copper, slip lines down to 100 Å are formed all over the surface, forming what they call 'elementary structure'. In alpha-brass, on the other hand, neither slip bands nor elementary structure are found, but a mass of randomly arranged slip lines or, in greater distortion, slip steps or terraces [figure 15]. They explain these observations in terms of two different mechanisms of plastic deformation. It is not yet sure, however, that an even better replica technique would not reveal still finer slip lines, possibly in both alloys and pure metals.

At a still finer level of structure, electron microscopy is providing direct evidence of those imperfections which are postulated in the dislocation theory of crystal growth and lattice strength. Growth spirals, a consequence of one type of lattice defect, are indeed visible in some crystals under the optical microscope, but Dawson [34], by using an elegant technique on lamellar crystals of long-chain compounds (figure 13), has provided evidence of their occurrence in the very earliest stages of crystal growth. He is able to show, by the metal-shadowing technique, whether growth steps are mono- or multi-molecular in height. In some of his electron micrographs the crystals appear to be simple monomolecular sheets, without imperfections, at the edges of which dislocations are formed during later deposition of molecules.

Still more experimental material for checking and extending dislocation theory is provided by direct observation of the molecular units in a lattice. Figure 9 shows the beginnings of a raft or ordered mono-layer of a plant virus, but the more advanced stages of growth are even more informative, as revealed in the beautiful micrographs obtained by R. W. G. Wyckoff and L. W. Labaw [35], using a combined metal-carbon replica technique (figure 12). Many of the micrographs again show a remarkable perfection of structure, considering that they have been dried before replication. When more than one face is exposed the complete crystal structure can be deduced.

Virus particles are about one hundred times greater in diameter than atoms, and the forces between them are different in nature and intensity. It cannot be assumed that in forming crystals they will necessarily obey the same laws as do atoms, and it is important to examine other types of lattice. The next step has now been taken by Menter [36], who has obtained pictures of a small molecular lattice without the intermediary of a replica. He chose the metal phthalocyanines for investigation, because of the favourable disposition of the metal atoms in planes which are almost normal to the flat face of the ribbon-like crystal. When resting on the supporting grid, therefore, the lattice will present what is effectively a set of parallel slits to the electron beam. Diffraction from the $20\bar{1}$ planes containing the metal greatly outweighs diffraction from the lighter atoms forming the rest of the molecule, so that in favourable orientation a direct image of the lattice is formed (figure 16). Owing to the extreme thinness of the crystals ($\sim$ 10 unit cells) the third Laue condition is so far relaxed that there is considerable latitude in orientation. Micrographs of the compound with platinum give a measured spacing of 11·97 Å for the $20\bar{1}$ planes, compared with the value of 11·94 Å from X-ray analysis. The agreement is not quite so good for the copper compound, probably because the $20\bar{1}$ planes are inclined at a greater angle (10°) to the normal to the flat face of the crystal. In one micrograph a remarkably clear case of a line dislocation was observed (figure 14), exactly according to the book. The metal-free compound, in which hydrogen replaces the metal, gives images of the lattice, although less well pronounced.

The structure of phthalocyanine was already known, but it may well be that electron microscopy will be able to assist in elucidating that of some other substances, suitably loaded with metal atoms. It should now also be possible to test directly theories of the variation of lattice parameters in very small crystals. The observation of lattice vacancies or interstitial material will depend upon a further improvement in resolution.

PRACTICAL LIMITATIONS OF ELECTRON MICROSCOPY

So far as lens aberrations are concerned, the modern electron microscope should be able to reach a resolving power of 2–3 Å, making visible individual atoms of high atomic number and the lattices of almost all crystals. The limiting factors are of a different nature: displacement and contamination of the specimen. The former includes thermal and electrical effects due to the impact of the beam on the specimen, mechanical vibration, fluctuations in the electrical supplies, and the effects of stray electric and magnetic fields. It is a matter of detailed design and testing to bring these influences under control or at least to minimize their effect on the image [37]. But even if a resolving power of a few Ångström units were available it would quickly be rendered useless as soon as the electron beam strikes the specimen, owing to the deposition of a blanketing layer upon it. This 'contamination' is carbonaceous and probably comes from residual material on and in the inner walls of the microscope. The rate of deposition is of the order of 1 Å per second, so that structural details near the limit of resolution are rapidly blotted out. It constitutes the greatest single hindrance to attaining in the electron image the resolving power of which the microscope is theoretically capable. The only practicable answer at present is to heat the specimen stage [38], since deposition does not occur if the temperature is above 200° C, but this expedient is not possible with biological specimens. The ultimate solution must involve a detailed investigation of the main origin of the contaminating substance, with consequent changes in materials used for the construction of the instrument and in their treatment.

Even when these problems have been solved and a resolving power of a few Ångströms has been demonstrated on selected test specimens, the difficulty will remain that most specimens of interest provide insufficient contrast for details of this order. Biological specimens at present rarely show resolution better than 20 Å where test preparations of colloidal metal show 10 Å or better. The low scattering power of elements of small atomic number is the reason, and part of the remedy will consequently be the development of specific heavy-metal stains. It will also be of value to eliminate from the imaging beam those electrons which have been inelastically scattered in the specimen and confuse the image owing to the chromatic error of the electron lenses. Correction of this defect would not appreciably improve contrast, but rejection of the inelastic component would do so. The design of suitable filter lenses is already practicable [39].

Only after these improvements have been perfected will it be profitable to develop a lens corrected for spherical aberration. Experiments so far made with correction elements [40] make it only too evident that they will introduce new requirements in electrical and mechanical stability. The last lap on the way to a resolving power of 1 Å is likely to be the longest and most troublesome.

REFERENCES

[1] KNOLL, M. and RUSKA, E. *Ann. Phys., Leipzig*, **12**, 647, 1932.
BRÜCHE, E. *Naturwissenschaften*, **20**, 49, 1932.

[2] BRETSCHNEIDER, L. H. *Proc. Acad. Sci. Amst.*, **52**, 654, 1949.
PEASE, D. C. and BAKER, R. F. *Proc. Soc. exp. Biol., N.Y.*, **67**, 470, 1948.

[3] COSSLETT, V. E. *Brit. J. appl. Phys.*, **7**, 10, 1956.

[4] SJÖSTRAND, F. S. *Experientia*, **9**, 114, 1953; *Z. Wiss. Mikr.*, **62**, 65, 1954.

[5] HODGE, A. J., HUXLEY, H. E., and SPIRO, D. *J. Histochem. Cytochem.*, **2**, 54, 1954.

[6] PORTER, K. R. and BLUM, J. *Anat. Rec.*, **117**, 685, 1953.

[7] HAANSTRA, H. B. *Philips tech. Rev.*, **17**, 178, 1955.

[8] SJÖSTRAND, F. S. 'Physical Techniques in Biological Research', Vol. III. Academic Press, New York. 1956.

[9] PALADE, G. E. and PORTER, K. R. *J. exp. Med.*, **100**, 641, 1954.

[10] GIBBONS, I. R. and BRADFIELD, J. R. G. *Biochim. biophys. Acta* (in press).

[11] ROSZA, G. and WYCKOFF, R. W. G. *Exp. Cell Res.*, **2**, 630, 1951.

[12] BRANDES, D., ZETTERQVIST, H.. and SHELDON, H. *Nature, Lond.*, **177**, 382, 1956.

[13] ROTHSCHILD, LORD. *Endeavour*, **15**, 79, 1956.

[14] BRADFIELD, J. R. G. *Nature, Lond.*, **173**, 184, 1954; 'Bacterial Anatomy' (6th Symposium, Soc. Gen. Microbiol.). University Press, Cambridge, 1956, p. 296.

[15] KELLENBERGER, E. and RYTER, A. *Schweiz. Z. Path.*, **18**, 1122, 1955.

[16] ROBINOW, C. F. *J. Hyg. Camb.*, **43**, 413, 1944.
ROBINOW, C. F. and COSSLETT, V. E. *J. appl. Phys.*, **19**, 124, 1948.

[17] GLAUERT, A. M. and BRIEGER, E. M. *J. gen. Microbiol.*, **13**, 310, 1955.

[18] DAWSON, I. M. and MCFARLANE, A. S. *Nature, Lond.*, **161**, 464, 1948.

[19] SCHRAMM, G., SCHUMACHER, G., and ZILLIG, W. *Z. Naturf.*, **10b**, 481, 1955.

[20] WILLIAMS, R. C. *Biochim. biophys. Acta*, **8**, 227, 1952.
HART, R. *Proc. nat. Acad. Sci., Wash.*, **41**, 261, 1955.

[21] MARKHAM, R. and HORNE, R. W. (unpublished).

[22] BRADLEY, D. E. *Brit. J. appl. Phys.*, **5**, 65 and 96, 1954.

[23] NUTTING, J. and SMITH, E. *Brit. J. appl. Phys.*, **7**, 214, 1956.

[24] COSSLETT, V. E. and JONES, D. *Proc. Int. Conf. Electron Micr., Paris*, 1950. Ed. Revue d'Optique, Paris. 213, 1953; *J. sci. Instrum.*, **32**, 86, 1955.

[25] FERT, C. C.N.R.S. Colloquium No. 58, Toulouse. April 1955.
FERT, C., MARTY, B. and SAPORTE, R. *C.R. Acad. Sci., Paris.* **240**, 1975, 1955.

[26] JONES, D. *Bull. Inst. Metals*, **2**, 235, 1955.

[27] MENTER, J. W. *J. Inst. Met.*, **81**, 163, 1952–3.

[28] MCMULLAN, D. *Proc. Instn elect. Engrs Pt.* II. **100**, 245, 1953.
SMITH, K. C. A. and OATLEY, C. W. *Brit. J. appl. Phys.*, **6**, 391, 1955.

[29] MÖLLENSTEDT, G. and DÜKER, H. *Optik*, **10**, 192, 1953.

[30] RATHENAU, G. W. and BAAS, G. *Physica, 's Grav.* **17**, 117, 1951; *Acta Metallurg.* **2**, 875, 1954.

[31] American Society for Testing Materials, subcommittee XI of committee E-4. *Proc. Amer. Soc. Test. Mater.*, **50**, 444, 1950; **52**, 543, 1952.

[32] HEIDENREICH, R. D. and SHOCKLEY, W. *J. appl. Phys.*, **18**, 1029, 1947.
BROWN, A. F. *Nature, Lond.*, **163**, 961, 1949.

[33] KUHLMANN-WILSDORF, D. and WILSDORF, H. *Acta Metallurg.* **1**, 394, 1953.

[34] DAWSON, I. M. *Proc. roy. Soc. A.*, **214**, 72, 1952.
ANDERSON, N. G. and DAWSON, I. M. *Proc. roy. Soc. A.*, **228**, 539, 1955.

[35] WYCKOFF, R. W. G. C.N.R.S. Colloquium No. 58, Toulouse. April 1955.

[36] MENTER, J. W. *Proc. rov. Soc. A.* (in press).

[37] HAINE, M. E. and MULVEY, T. *Proc. Int. Conf. Electron Micr., London*, 1954. Royal Microscopical Society, London. 1956; *J. sci. Instrum.*, **31**, 326, 1954.

[38] ENNOS, A. E. *Brit. J. appl. Phys.*, **5**, 27, 1954.

[39] BOERSCH, H. *Z. Phys.*, **134**, 156, 1953.
RANG, O. *Optik*, **11**, 328, 1954.

[40] SCHERZER, O. *Proc. Int. Conf. Electron Micr., Paris*, 1950. Ed. Revue d'Optique, Paris. 191, 1953.
MÖLLENSTEDT, G. *Proc. Int. Conf. Electron Micr., London*, 1954. Royal Microscopical Society, London. 1956.

[41] YOUNG, J. Z. *Endeavour*, **15**, 5, 1956.

Book reviews

THE FUTURE OF MAN

The Foreseeable Future, *by Sir George Thomson. Pp. vii* + 166. *Cambridge University Press, London.* 1955. 10*s.* 6*d. net.*

This is a fascinating book because of its intimate personal quality. Sir George gives us his forecast of technical advances and of the results of their impact on human society in the near future. His thoughts range over a wide field, and the book is full of shrewd reflections and sly touches of humour. The analytical approach of the physicist, unwilling to leave things as vague qualitative generalizations, keeps peeping out and is seen at its best in the chapter on transport and communications. The simple calculations forecasting the future of travel by air, sea, and land, of interplanetary flight, and of television reveal clearly, even to the layman, the possibilities and limitations of each. Sir George is an optimist and does not allow himself to be worried unduly by the problems of the increase of population and food supply. But he is concerned about man's ultimate future. 'Civilized mankind at present is rather like a child that has been given too many toys for its birthday.' How will he use them, and how will he use the leisure that will come from the automatic factory—in some creative work, or in the pursuit of adventure like space travel? The answer, he thinks, may come from our increasing knowledge of the working of the brain, which may release us from a tangle of hindrances that come from wrongly sorted impressions. 'Man may expect a glorious future.' HAROLD HARTLEY

EXPERIMENTAL DESIGN

Experimental Design and its Statistical Basis, *by D. J. Finney. Pp. xi* + 169. *Cambridge University Press, London.* 1955. 30*s. net.*

Dr Finney contributes this book to a series for workers in biology and medicine, and his examples are chosen from these fields. But his emphasis is not on elementary descriptions of standard designs. Rather, it gives a penetrating discussion of practical ways of deriving the maximum benefit from experimental work, opening and closing with general chapters on this theme and emphasizing the value of statistical consultation undertaken sufficiently early and thoroughly in a research programme. This applies to industrial and laboratory experiments, as to all others, and the book will therefore have a general appeal.

Two chapters cover methods of dealing both with observations classified into groups and with actual measurements. Chapters on standard methods of design are illustrated with thorough discussion of examples, and industrial research workers will note with interest comments on the use of designs to compare methods of technique. The chapters on factorial experimentation and sequential methods will certainly be very useful to chemists; interest in biological assay also is by no means confined to pure biologists. Reading will be somewhat easier, naturally, for those who have some basic knowledge of statistical method, but the book should find a place in the libraries of all research departments. G. M. CLARKE

NUMERICAL ANALYSIS

Numerical Analysis, *by Z. Kopal. Pp. xiv* + 556. *Chapman and Hall Limited, London.* 1955. 63*s. net.*

This volume provides a systematic and comprehensive introduction to the theory and practice of the numerical analysis of functions of a single real variable. Professor Kopal has succeeded in producing a most stimulating and inspiring account of this most important development in mathematics as applied to problems of the real physical world. The subject is presented in a most attractive and charming style, and the individual chapters are enriched with biographical notes which are of very considerable interest and which often throw a great deal of light on the historical development of the subject. The carefully selected problems at the end of each chapter provide a searching examination of the grasp the reader has formed of the subjects treated.

The order of presentation of the subject is polynomial interpolation, numerical integration, and integration of ordinary differential equations. This is followed by an account of boundary value problems as solved by algebraic, variational, iterative, and other methods. After an account of mechanical quadratures, the author concludes by discussing the numerical solution of integral and integro-differential equations. The volume will doubtless come to be one of the standard textbooks on this important subject. G. TEMPLE

HISTORY OF THE TELESCOPE

The History of the Telescope, *by H. C. King. Pp. xvi* + 456. *Charles Griffin and Company Limited, London.* 1955. 50*s. net.*

The need for a comprehensive history of the telescope has long been felt. Dr King has filled the lacuna by a study exemplary in scholarship and detail; clearly it will stand as an indispensable work of reference and as a source of information unobtainable elsewhere.

A feature rare in historical accounts because of the great difficulty involved, it continues the story to the present day —even including details of radio-telescopes still in construction. The last hundred years of telescope-making occupy more than half the book, so there has resulted an inevitable but unwelcome curtailing of the earlier history. The reader must be warned that the treatment in this book is at an opposite pole to that of the companion volume —'The History of the Microscope' by R. S. Clay and T. H. Court—which was published by the same firm in 1932 and has since become a classic. They treated the microscope from an antiquarian standpoint, giving lists and biographies of known makers, concentrating attention on earlier models, and ending at the invention of the achromatic instrument. Dr King seems more at home in the modern observatory and the library rather than in the museum, and he relies chiefly on printed accounts to illustrate the history of the scientific design. Consequently his treatment of pre-telescopic instruments is weak, and he quite omits the fine and important vellum-tubed telescopes, common in museums but not in literature. Thus he even misses the earliest English telescope, now at Greenwich, made by Jacob Cunigham in 1661. DEREK J. PRICE

DIAMOND CRYSTALLOGRAPHY

Microstructures of Diamond Surfaces, *by S. Tolansky. Pp. viii* + 67. *N.A.G. Press Limited, London.* 1955. 40*s. net.*

The transition in recent years of industrial diamonds from the status of a worthless by-product to their role of strategic material in several branches of technology, has attracted the attention of many individuals and laboratories to the remarkable properties of crystalline carbon.

The elegant and useful optical techniques of Professor Tolansky have been applied lately by his school to studies on the microstructure of diamond surfaces. In a small monograph Professor Tolansky has summarized the results of the investigations he has so ably directed in this field. The volume is written in a manner which will appeal to technical workers in many spheres besides those of optics and crystallography. The lucidity of the text is enhanced by the excellent reproduction of many remarkable photographs selected as illustrations.

The author emphasizes that his book is essentially a preliminary report, and the reviewer is one of many who will eagerly await the future appearance of an enlarged edition, in which we hope advances of knowledge will throw more light on the relationships between diamond surfaces and the properties of industrial stones, the origin of natural diamonds, and factors involved in the recent production of synthetic diamonds.

ROLAND S. YOUNG

NUCLEAR PHYSICS

Nuclear and Radiochemistry, *by G. Friedlander and W. Kennedy. Pp. ix* + 468. *John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1955. 60*s.* net.

This book discusses the fundamental facts of nuclear physics. To British eyes the title is misleading, but in the United States 'nuclear chemistry' is synonymous with 'transmutation of elements.' Thus only two out of thirteen chapters and a small section on target chemistry deal—by no means fully—with what in Britain would be considered chemical aspects. There is little or nothing about chemical manipulation of highly active materials, about shielding problems, glove-box techniques, remote handling, or even the chemistry of the heavy elements.

As an introduction to the field of radioactivity and nuclear transmutations, however, the book does full justice to its material. Well balanced chapters deal with the structure and the reactions of nuclei as well as with the techniques of radioactive measurement. The chapter on nuclear energy, written before the releases of the Geneva Conference on Atomic Energy (1955), is no longer adequate and will no doubt be rewritten in a future edition. Among the matters discussed are cosmic problems, such as nuclear processes in stars and the formation of the terrestrial elements. A series of appendices on nuclides and their physical properties completes a book which is exceedingly well written and which can be recommended not only as a textbook for the student, but also as a useful reference book.

E. GLUECKAUF

ELECTRON OPTICS

Optique Electronique, Volume I: Lentilles Electroniques, *by P. Grivet, M. Y. Bernard, and A. Septier. Pp.* 184. *Bordas, Paris.* 1955. *Fcs* 1450 *net.*

The present volume is the first of a series of three which will cover the applications as well as the theory of electron optics. It provides a clear and concise account of the principles and properties of magnetic and electrostatic electron lenses. The approach is from comparatively simple physical principles, so that it avoids being a specialist tract and should be understandable by any graduate in physics or mathematics. Where the Germans would offer a *Handbuch* of four times the length, and the Americans an embalmed lecture course starting from elementary definitions, the French by judicious selection have produced what is perhaps the best balanced and most useful treatment of the subject yet to appear. As M. L. de Broglie notes in his preface, the authors are always at pains to keep theory in contact with practical problems. Methods of measurement are given for electron lens properties and electromagnetic field distributions, as well as a full mathematical derivation of ray paths and aberrations. Practical details of the design and construction of electron lenses are included. If electrostatic lenses receive fuller mention than the magnetic type, it is a reflection of the main preoccupation of Professor Grivet's laboratory. The final chapter deals with the recently developed method of 'strong focusing', in preparation for the discussion of particle accelerators in volume three.

V. E. COSSLETT

MEDICINE AND NUCLEAR PHYSICS

Medicina Nucleare, *by A. Perussia. Pp. xii* + 877. *Il Pensiero Scientifico, Rome.* 1954. *Lire* 7000.

The main feature and the greatest virtue of this book are its directness and simplicity. It is therefore valuable for all readers who, although interested in the practical applications of the isotopic tracers, yet do not command a specialized knowledge of nuclear physics. The radioactive isotope techniques, already used in many fields of scientific investigation, make it necessary for the research worker to be up to date in the different aspects of these new methods. Often doctors, physiologists, pharmacologists, and even chemists can obtain only a superficial understanding from their readings of the large literature available in this specialized field, and most of the facts related to radioactivity and its effects on matter tend to remain rather hazy. We must be grateful to Professor Perussia and his collaborators for this book, in which a number of intricate ideas are explained clearly and comprehensively, without demanding too wide a knowledge of mathematics and physics from the readers, and yet fully describing the possible applications and methods of radio-biochemistry and the modern developments of radiotherapy. In a book of this scope it is no disadvantage that in the first part some of the subjects of a strictly physical character have been dealt with rather briefly. All who are interested in the use of isotopes as tracers and as therapeutic agents will find this book extremely useful.

MAURIZIO ZIFFERERO

GENERAL PHYSICS

Principles and Applications of Physics, *by Otto Blüh and Joseph D. Elder. Pp. xiv* + 866. *Oliver and Boyd Limited, London.* 1955. 45*s. net.*

This is a general textbook of physics which, in standard, lies in the field somewhere between the intermediate and the pass degree, and will appeal, in universities and technical colleges, to those who need a simple and comprehensive guide to the subject and to other students, who are going further, as a general introduction. It will also be welcomed by many who, not confronted with examinations, want an up-to-date elementary exposition of the whole field of physics, including recent applications.

The book is notable for the wide ground covered and especially for the brief descriptions of very recent work of which many have heard without knowing very clearly what is in question. Thus transistor and thermistor, photomultiplier tube, ferroelectricity, semiconductor, anti-*g* suit, coated lenses, cosmic rays, the cavity magnetron, the superheterodyne circuit, the electron microscope, the phase-contrast microscope, supersonics, the Mount Palomar telescope, and many more products of the last twenty years or so all come in for mention. Not very much is, perforce, said of each, and if there is to be a criticism, it is that the principles are not much stressed, even when they are simple and revealing. Thus we are told of the directional properties of supersonic waves, but little is said of the cause of these properties, although a very useful and general lesson is involved.

To make room for the very modern developments the discussion of certain of the fundamental matters, such as specific heats—and, in fact, the subject of heat in general—suffers somewhat. The standard properties of matter are not very convincingly handled. On the other hand, attention is devoted to the medical applications of physics and to the inanimate aspects of television, while a considerable chapter deals with nuclear physics, including the most modern aspects. The final chapters deal with the philosophy of physics and with the general place of physics in the world of today.

In general the authors have produced an extraordinarily inclusive and very lively book, which will answer satisfactorily the questions provoked by reading in the popular press of the physics of today, if not some of the simpler and more fundamental queries in elementary physics that occur to the occasional reflective mind.

E. N. DA C. ANDRADE

THE LAWS OF NATURE

The Laws of Nature, *by R. E. Peierls. Pp.* 284. *George Allen and Unwin Limited, London.* 1955. 21*s. net.*

Is it possible to convey to the ordinary educated man in the limited space of one moderate volume the whole of physics from Galileo to the renormalization of mass and heavy mesons? Professor Peierls has certainly made a gallant attempt. Whether he has succeeded or not the present writer is not quite sure, but he feels pretty certain that if Peierls has failed the thing cannot be done. This is a fascinating book for a physicist to read quickly, seeing the whole of his subject pass in panorama before his eyes, rather as a man may view a familiar country from the air. The book is well written and illumines the scene with many flashes of wisdom. There is very little mathematics, but such a treatment presupposes the mental attitude of a man who thinks naturally in mathematics. It would be a most interesting experiment if some far-sighted headmaster would try this book on his classical sixth: if they could grasp it—and there is no knowledge assumed that they would not have had—they would have a better understanding of the meaning of physics than many science graduates. The difficulty of physics lies in the ideas, which sound simple but are deceptively subtle: I have heard a Nobel Prize-winner stumble badly on a bit of dynamics. It is to my mind doubtful if anyone can grasp these ideas quickly; they need time to sink in. Besides Newtonian dynamics there are the ideas of entropy as a measure of disorder, of wave motion, of fields of force and their associated potentials, of electrodynamics as a connected whole, of relativity, of the quantum theory and its relation to probability, to name only a few of the most important.

If a man cannot give time to understand these ideas, how far will a superficial acquaintance with them help him? Perhaps more than the professional teacher of physics is usually inclined to admit. Though he may not really understand the ideas in the sense of comprehending them in the round, he will, one may reasonably hope, see them as outlines, though misty ones, and perhaps most important of all be able to reject many views that are wholly incompatible with them. For the man who wishes to get such a view Professor Peierls' book is admirable.

G. P. THOMSON

QUANTUM THEORY OF SOLIDS

Quantum Theory of Solids, *by R. E. Peierls. Pp. vi* + 229. *Clarendon Press, Oxford.* 1955. 30*s. net.*

This volume provides a general introduction to a number of fundamental problems in the quantum theory of solids. The dynamical theory of crystal lattices and phenomena involving the interaction and scattering of photons, to the understanding of which Professor Peierls has made an important contribution, are covered by valuable sections. The chapters on the electron theory of solids, cohesion in metals, transport phenomena, and magnetic properties give a clear presentation of these subjects. The only references to the more practical aspects of the physics of the solid state are contained in the chapter on semiconductors and luminescence. Here it is to be regretted that there is no mention of germanium, because many of the fundamental properties of semiconductors are best exemplified by the results of experimental work with this important material. The book concludes with a review of the Frölich-Bardeen theory of superconductivity and a summary of the difficulties encountered in the theoretical discussion of the model.

The limitations imposed by the simplified models which alone are amenable to theoretical discussion and the assumptions made in the derivations are noted throughout the book, and there are clear statements of the physical significance of the results of the mathematical investigations. These two features will be appreciated by theoretical and experimental physicists alike.

J. W. MITCHELL

ORGANIC CHEMISTRY

Schmidt's Organic Chemistry (*seventh edition*), *revised and edited by N. Campbell. Pp. xi* + 936. *Oliver and Boyd Limited, Edinburgh and London.* 1955. 35*s. net.*

Schmidt's original work, published in 1906, was called *Kurzes Lehrbuch der organischen Chemie*. The third (1922) German edition was already a formidable affair, and the present volume represents the result of repeated revision of the first English edition, published in 1926. It contains many remnants of the first translation, and Dr Campbell has done remarkably well to keep the book from outgrowing its strength. The revisions include sections on the structural applications of ultra-violet and infra-red spectroscopy, the conformation of cyclohexanes, nucleotides, nucleic acids, nucleophilic and homolytic substitution of aromatic compounds, polysaccharides, and other topics of current interest.

It is a pity that some benzene rings are written without three double bonds while others, sometimes on one and the same page, are written in what is at the moment the accepted style. As is almost inevitable in so large a work, some points have escaped correction. The account of the chemistry of urea is not particularly up to date. The stereochemistry of the tartaric acids might have been given more space, if only in view of recent work on absolute configurations. No mention is made of how formamide is made, or how it differs from true acid amides. On the whole, however, the book presents a balanced view of the more important branches of organic chemistry.

There is an author index as well as a good subject index. The volume is excellently printed.

E. E. TURNER

CHEMISTRY OF HYDROCARBONS

The Chemistry of Petroleum Hydrocarbons, *edited by B. T. Brooks, C. E. Boord, S. S. Kurtz, and L. Schmerling.* Volume 1, *pp. viii* + 664; Volume 2, *pp. vi* + 448; Volume 3, *pp. vii* + 690. *Reinhold Publishing Corporation, New York; Chapman and Hall Limited, London.* 1955. 144*s. net*, 108*s. net*, and 144*s. net respectively.*

It is hardly possible in a brief review to convey an adequate idea of the richness of the contents of these three volumes. The fifty-nine chapters, by some sixty different authors drawn mainly from oil companies and teaching and research institutions, several by one or other of the distinguished editors, cover most conceivable aspects of hydrocarbon chemistry, the hydrocarbons including paraffins, olefins, alicyclics (naphthenes), aromatics, and the hybrid classes. The first six chapters deal with the compositions of petroleums and their possible origin. The next ten are concerned with methods of separation of the components and with analysis and identification, e.g. with extractive and azeotropic distillation, infra-red and Raman spectra, and mass spectroscopy. Five chapters deal with the synthesis of hydrocarbons, including one on the Fischer-Tropsch process, and these are followed by ten important chapters on the thermal treatment of the hydrocarbons, thermal and catalytic cracking, aromatization, reforming, hydroforming, 'platforming.' The theory of catalytic cracking is discussed in a fascinating manner by B. S. Greenfelder, making free use of the carbonium ion theory. Other chapters discuss different aspects of the oxidation of hydrocarbons, and a number of miscellaneous chapters deal with halogenation (including fluorination), nitration, isomerization, and polymerization of olefins. A long chapter on aromatic substitution (114 pages) is planned in an unusual but interesting way, with special emphasis on alkylation. It is followed by one on industrial applications of the alkylation of aromatic hydrocarbons, discussing particularly the production of ethylbenzene from benzene and ethylene (for styrene) and of higher alkylbenzenes (for the manufacture of detergents). The emphasis throughout is on scientific principles, not technological practice.

With few exceptions the contributions are clearly written and their subject matter well arranged and presented; many of them, with their critical accounts of the results of recent research, must be of interest to a far wider circle of chemists than those engaged in the petroleum industry. The reviewer had a strong impression that the utility of the work would have been enhanced by an introduction explaining the layout of the work, more cross-references, and, for the reader not well versed in the language of oil chemists, a glossary of technical terms and abbreviations.

E. H. RODD

PHYSICAL CHEMISTRY

Physical Chemistry, *by Farrington Daniels and Robert A. Alberty. Pp. vii* + 671. *John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1955. 52*s. net.*

This is a sound introduction to physical chemistry for university students. Its chief merits are a very clear and concise exposition of the main experimental facts and their interpretation, which can be recommended to students who find the subject difficult; there are selected references to more advanced books and to original papers for those whose interest is aroused. Each chapter contains a number of calculations worked out as examples and about thirty numerical problems, some with, and some without, answers.

After a discussion of the states of matter, eight chapters are devoted to thermodynamics. The approach is a functional one, the phase rule is proved and applied to systems containing up to three components, and the treatment of chemical equilibria includes the third law and a brief account of statistical mechanics. In the section on electrochemistry a distinction is admitted between the experimental concept of electrode potential and the derived ideas of oxidation and reduction potentials; there is thus hope of reconciliation between the different conventions in use on the two sides of the Atlantic. Colloids and nuclear chemistry are well covered, but the chapter on chemical kinetics might have been brought more fully up to date. Relatively little space is given to molecular structure, and the unifying role of quantum theory is not emphasized.

K. W. SYKES

ANALYSIS OF DRUGS

The Quantitative Analysis of Drugs (*second edition*), *by D. C. Garratt. Pp. xv* + 670. *Chapman and Hall Limited, London.* 1955. 70*s. net.*

The first edition of this book, which was published in 1937, appeared under the title 'Drugs and Galenicals: Their Quantitative Analysis'. The revision of the earlier text has increased the number of pages by over 50 per cent, the enlargement being accounted for mainly by the introduction of new matter in some of the monographs previously presented, by the addition of over thirty new monographs, by the inclusion of a new chapter on physical methods, and by the incorporation of two new appendices covering respectively 'Extraneous matter in food and drugs' and 'Titration in non-aqueous solvents'. A cross-indexed supplement is also included to correlate the text with changes in the subject-matter of the British Pharmaceutical Codex which were introduced in the new edition, which appeared while Garratt's book was in press.

The wise drug analyst will follow the advice given by the author in his preface to check, whenever possible, the results obtained by one method by applying another, and preferably fundamentally different, analytical technique. As an aid to the adoption of this recommendation, the many methods abstracted from the British Pharmacopoeia or British Pharmaceutical Codex which appear in the monographs of Garratt's book are liberally supplemented by other procedures. 'The Quantitative Analysis of Drugs', in which misprints are scarce, is a useful adjunct to these two standard works and can be recommended to chemists who are called upon to make analyses of drugs. In their possession it is likely to spend more time on the laboratory bench than on the library shelf.

A. J. AMOS

PALAEONTOLOGY

Stratigraphical Palaeontology (*second edition*), *by E. Neaverson. Pp. xii* + 806. *Clarendon Press, Oxford.* 1955. 105*s. net.*

The second edition of Dr Neaverson's well known 'Stratigraphical Palaeontology' has been greatly enlarged (from 525 to 806 pages) by the interpolation of sections dealing with extra-British marine faunas grouped under 'faunal regions.' The sections on British faunas to which these have been added seem to be only slightly modified, and the result is a presentation that remains essentially insular. A few new figures have been prepared, together with a number of small-scale maps 'to indicate the distribution of facies in certain critical areas.' It is a pity that the trilobite figures at least could not be redrawn, for many of these are incorrect in detail, and even the magnifications given are often unreliable, but other groups of fossils seem better served.

The single-handed compilation of an advanced textbook such as this, surveying the whole succession of faunas from Cambrian to Pliocene on a world scale, is a vast undertaking. Inevitably specialists will find matters for criticism in the selection, content, and balance in particular sections, and inevitably also such a work will be more or less out of date by the time it is published. In the present instance, some wartime and post-war references are included in the literature lists, but it does not always follow that they are fully incorporated in the text. O. M. B. BULMAN

HORMONES IN REPRODUCTION

British Medical Bulletin, Volume 11, No. 2 (Hormones in Reproduction), *edited by A. S. Parkes. Pp.* 83 + 170. *Medical Department, The British Council, London.* 1955. 15*s. net.*

The time of publication of this issue of the British Medical Bulletin was well chosen. It was fifty years from the day in 1905 when Marshall and Jolly gave a paper to the Royal Society on 'The ovary as an organ of secretion'. Their recognition at that time of the functions of the follicular and luteal hormones set reproductive endocrinology upon a course of astonishing development. Introduced by a preface by A. S. Parkes, a neat historical summary of those discoveries that hastened progress, the papers by authorities in Britain and the Dominions are confined mainly to recent advances in research upon the reproductive system. They offer a very full account of certain topics: the reaction of the reproductive system to external stimuli and neurohumoral effects; the physiology and chemistry of gonadotrophins, oestrogens, and androgens; mammary growth, problems of fertility in man and farm animals; chemical and biological assays of sex hormones; and the effects of the adrenal and posterior pituitary gland upon reproduction. They are valuable for their full picture of knowledge of the reproductive systems of several species, and for the presentation of many intriguing and puzzling questions that remain unanswered.

J. R. P. O'BRIEN

OCCUPATIONAL MEDICINE

The Diseases of Occupations, *by Donald Hunter. Pp. xv* + 1046. *English Universities Press Limited, London.* 1955. £5 5*s. net.*

At long last Dr Donald Hunter has given us the benefit of his wide knowledge of occupational medicine in a remarkable textbook, which must surely become in Britain the standard work on this subject. This is a history book, a teacher of clinical medicine, and a text of public health; it will be of value to medical students, nurses, general practitioners, industrial medical officers, and consultants.

In a work of this size there are inevitably a few omissions; for example, there is no mention under occupational cancers of the risk of cancer of the lung in gas workers, nor of the comprehensive review by Hueper (1953) of occupational cancer. The account of the examination of young entrants into industry is out of date and does not mention the Factory Act of 1948. Perhaps some mention could have been made of the hazards of student life and the part played by the student health services, also the value of epidemiology in the study of occupational disease and the work of the industrial psychologist. However, these are trivial matters, and are probably due to the fact that Dr Hunter writes as a general physician practising in a great London teaching hospital. One notable feature of the book is the large number (438) of very fine illustrations. W. HOBSON

TUBERCULOSIS AND LEPROSY

Experimental Tuberculosis (with an Addendum on Leprosy), *edited by G. E. W. Wolstenholme and Margaret P. Cameron, assisted by Cecilia M. O'Connor. Pp. xii* + 396. *J. and A. Churchill Limited, London.* 1955. 42*s. net.*

Tuberculosis is still one of the greatest threats to the health of mankind, and although modern treatments with antibiotics and chemotherapeutics happily continue to lessen dramatically the mortality from the disease, its incidence continues as high as ever.

In order to focus attention on the many problems outstanding in this field the Ciba Foundation called together, under the chairmanship of Dr A. D. Rich, a group of about forty international experts interested in fundamental research on both the tubercle bacillus and the host. Their papers and the important discussions, together with a small symposium on closely related problems in leprosy, are now presented in book form.

A wide variety of topics, chemical, biological, and immunological, were discussed. Two points were outstanding in these discussions, one being the astonishing complexity of the chemistry of the bacillus and the other the almost complete lack of precise biochemical knowledge regarding the mechanism of hypersensitivity reactions and of acquired immunity. Scientists interested in any aspect of infectious disease will find much food for thought in this book, while young medical scientists looking for a major topic for study will hardly fail to get many new ideas. A study of the relationship between lipopolysaccharides and immunity offers an immediate challenge.

M. STACEY

RESEARCH FILMS

Research Films in Biology, Anthropology, Psychology and Medicine, *by Anthony R. Michaelis. Pp. xvi* + 490. *Academic Press Inc., New York; Academic Books Limited, London.* 1955. $10.

No worker in the fields covered by this book who is using cine-film, or intends to use cine-film, as a research technique can afford to be without Dr Michaelis's monumental work. The reference list of authors of scientific papers, books, and research films, containing well over 1500 references and occupying 90 pages, is alone worth the money. Not only does this book bring us up to date, it provides the only really complete account in English of the history of the research film in the field of the natural sciences.

A most valuable feature of this book is that it includes techniques from a number of related fields set out in an orderly and comprehensive way so that those working in psychology may learn from the experience of medical research workers, and so on. The practical possibilities of the interchange of information and experience have hardly existed before, except on a limited and national basis. Many who have not ventured to use films in research because of inexperience and the lack of expert guidance will be encouraged to use this most neglected but useful technique. Those who have been sceptical of the value of the film as a medium for recording and analysis will be completely convinced by the mass of evidence which is given here.

H. R. HEWER

Some books received

(*Note*. Mention of a book on this page does not preclude subsequent review.)

ASTRONOMY

Making and Using a Telescope, *by H. P. Wilkins and P. Moore. Pp.* 160. *Eyre and Spottiswoode (Publishers) Limited, London.* 1956. 12*s.* 6*d. net.*

BIOLOGY

Pelican in the Wilderness. A Naturalist's Odyssey in North America, *by F. F. Darling. Pp.* 380. *George Allen and Unwin Limited, London.* 1956. 25*s. net.*

BOTANY

Bibliographie der Pflanzenschutzliteratur 1951, *edited by J. Bärner. Pp. xliv* + 420. *Biologische Bundesanstalt für Land- und Forstwirtschaft, Berlin.* 1955. *DM* 38 *net.*

Cultures Tropicales 1. Plantes Vivrières, *by R. Cerighelli. Pp. xxxv* + 635. *J.-B. Baillière et Fils, Éditeurs, Paris.* 1955. *Fcs* 4800 *net.*

Species Studies in the British Flora. B.S.B.I. Conference Reports, Number 4, *edited by J. E. Lousley. Pp.* 186. *The Botanical Society of the British Isles, London.* 1955. 20*s. net.*

CHEMISTRY

Lehrbuch der Organischen Chemie, Volume 3/4, *by H. Beyer. Pp. xvii* + 690. *S. Hirzel Verlag, Leipzig.* 1955. *DM* 22.50 *net.*

Les Lacunes des Cristaux et leurs Inclusions Fluides, *by G. Deicha. Pp.* 126. *Masson et Cie., Paris.* 1955. *Fcs* 950 *net.*

Lithium Aluminium Hydride in Organic Chemistry, *by V. M. Micovic and M. L. Mihailovic. Pp. xi* + 193. *Serbian Academy of Sciences, Belgrade.* $3 *net.*

Nuclear Level Schemes A = 40 – A = 92 (covering the Elements Ca–Zr), *by K. Way, R. W. King, C. L. McGinnis, and R. van Liesbout. Pp. xx* + 221. *National Academy of Sciences, National Research Council, Washington, D.C.* 1955. $1.75 *net.*

Organic Syntheses, Volume 35, *edited by T. L. Cairns. Pp. vi* + 122. *John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1955. 30*s. net.*

Porphyrin Biosynthesis and Metabolism (a Ciba Foundation Symposium), *edited by G. E. W. Wolstenholme and E. C. P. Millar. Pp. xii* + 308. *J. and A. Churchill Limited, London.* 1955. 30*s. net.*

Principles of Organic Chemistry (*second edition*), *by James English, Jr., and H. G. Cassidy. Pp. xiii* + 469. *McGraw-Hill Book Company Inc., New York; McGraw-Hill Publishing Company, London.* 1956. $6.50 *net.*

Resonance in Organic Chemistry, *by G. W. Wheland. Pp. xiii* + 846. *John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1955. 120*s. net.*

Structure Reports for 1942–44, Volume 9, *edited by A. J. C. Wilson. Pp. viii* + 448. *Published for the International Union of Crystallography by A. Oosthoek's Uitgevers Mij., Utrecht.* 1955. *Fl.* 65 *net.*

GENERAL

Clays and Clay Minerals (Proceedings of the Second National Conference on Clays and Clay Minerals), *edited by A. Swinford and N. Plummer. Pp. viii* + 504. *National Academy of Sciences, National Research Council, Washington, D.C.* 1954. $4 *net.*

Cybernetics (Transactions of the Tenth Conference, April 22–24th, 1953), *edited by H. von Foerster. Pp.* 100. *Sponsored by the Josiah Macy, Jr., Foundation, New York.* 1955. $2.75 *net.*

Gestalter Unserer Zeit. Forscher und Wissenschaftler im Heutigen Europa, Volumes 3 and 4. Physiker, Chemiker, Astronomen, Erforscher der Erde, Mathematiker, Mediziner, Biologen, Anthropologen. Volume 3, *pp.* 379; Volume 4, *pp.* 339. *Gerhard Stalling Verlag, Hamburg.* 1955. *DM* 16.80 *net per volume.*

The Mechanical Properties of Textile Fibres, *edited by R. Meredith. Pp. xii* + 333. *North-Holland Publishing Company, Amsterdam.* 1956. 61*s. net.*

Physical Properties of Wool Fibres and Fabrics. Volume 2, Wool Research. *Pp. vi* + 234. *Wool Industries Research Association, Leeds.* 1955. 30*s. net.*

Sixième Rapport Annuel, 1953. *Pp.* 229. *Institut pour la Recherche Scientifique en Afrique Centrale, Brussels.* 1956. *Fcs* 80 *net.*

Der Tropische Regenwald, *by E. Bünning. Pp. viii* + 118. *Springer-Verlag, Berlin.* 1956. *DM* 7.80 *net.*

GEOLOGY

Précis de Géologie (*second edition*), *by L. Moret. Pp. viii* + 669. *Masson et Cie., Éditeurs, Paris.* 1955. *Paper covers, fcs* 2400 *net; bound, fcs* 3000 *net.*

MEDICINE

Ergebnisse der Medizinischen Grundlagenforschung, Volume 1, *edited by K. F. Bauer. Pp. vi* + 855. *Georg Thieme Verlag, Stuttgart.* 1956. *DM* 129 *net.*

German Medical Journal, Volume 1, No. 1, January 1956, *edited by G. R. Graham. (Monthly English Language edition of the* Deutsche Medizinische Wochenschrift, *edited by L. Heilmeyer.) Pp.* 36. *Georg Thieme Verlag, Stuttgart.* 1956. *Subscription per year DM* 17.60 *net.*

Speicherung. Stoffanreicherung im Retikuloendothel und in der Niere, *by N. Jancsó. Pp.* 468. *Akadémiai Kiadó, Budapest.* 1955. 130 *Forint.*

METALLURGY

Chromium Nickel Austenitic Steels, *by F. H. Keating. Pp. x* + 138. *Butterworths Scientific Publications, in association with Imperial Chemical Industries Limited, London.* 1956. 25*s. net.*

PHYSICS

The Analytical Theory of Heat, *by J. Fourier, translated, with notes, by A. Freeman. Pp. xxiii* + 466. *Dover Publications Inc., New York.* 1955. $1.95 *net.*

Annual Review of Nuclear Science, Volume 5, *edited by J. G. Beckerley. Pp. ix* + 448. *Annual Reviews Inc., Stanford, California.* 1955. $7 *net.*

Atoms and the Universe, *by G. O. Jones, J. Rotblat, and G. J. Whitrow, with a prefatory note by Sir John Cockcroft. Pp.* 254. *Eyre and Spottiswoode (Publishers) Limited, London.* 1956. 25*s. net.*

Boundary Layer Effects in Aerodynamics. (Proceedings of a Symposium held at the National Physical Laboratory on 31st March and 1st April, 1955.) *Pp. xiv* + 396. *Her Majesty's Stationery Office, London.* 1956. 30*s. net.*

Champs de Vecteurs et de Tenseurs. Introduction à l'Électro-Magnétisme, *by E. Bauer. Pp. vii* + 204. *Masson et Cie., Editeurs, Paris.* 1955. *Fcs* 2200 *net.*

Mass-Transfer Operations, *by R. E. Treybal. Pp. ix* + 666. *McGraw-Hill Book Company Inc., New York,* 1955. $9.50 *net.*

Surveys in Mechanics. The G. I. Taylor Seventieth Anniversary Volume, *edited by G. K. Batchelor and R. M. Davies. Pp.* 475. *Cambridge University Press, London.* 1956. 50*s. net.*

ZOOLOGY

Principles of Embryology, *by C. H. Waddington. Pp. x* + 510. *George Allen and Unwin Limited, London.* 1956. 45*s. net.*

Notes on contributors

H. S. W. MASSEY

B.A., M.Sc., Ph.D., F.R.S.,

Was born in 1908 and was educated at the University High School, Melbourne, and Melbourne University. After graduation he undertook research work in atomic physics at the Cavendish Laboratory, Cambridge. In 1933 he was appointed head of the department of mathematical physics at Queen's University, Belfast, and in 1938 became Goldsmid professor of mathematics at University College, London. He held this chair until 1950, when he became Quain professor and head of the department of physics at the same college. In addition to many papers and reviews in scientific journals he is joint author of two monographs, 'The Theory of Atomic Collisions' (with N. F. Mott) and 'Electronic and Ionic Impact Phenomena' (with E. H. S. Burhop), and has also written two other books.

E. N. DA C. ANDRADE,

D.Sc., Ph.D., LL.D., F.R.S.,

Was born in London in December 1887 and was educated at St Dunstan's College, the Universities of London, Manchester, and Heidelberg, and the Cavendish Laboratory, Cambridge. He served as an artillery officer in France in the war of 1914–18, and afterwards was for some years professor at the Artillery College (later the Royal Military College of Science). In 1928 he was appointed Quain professor of physics in the University of London. At University College he established a flourishing school of physics, known for fundamental work on the mechanical properties of the solid and liquid state. In January 1950 he was appointed Director in the Royal Institution of Great Britain and Director of the Davy Faraday Research Laboratory, but in 1952 resigned, like his predecessor. He maintains close connection with colleagues overseas, and is *Membre Correspondant de l'Académie des Sciences, Institut de France.* He is known for the clarity of his exposition of science, both in writing and by lectures.

C. E. H. BAWN,

C.B.E., B.Sc., Ph.D., F.R.S.,

Was born in 1908 and was educated at Cotham Grammar School and the University of Bristol. After being a Lecturer in the University of Manchester and Reader in the University of Bristol, he was appointed Professor of Inorganic and Physical Chemistry in the University of Liverpool in 1948. During the war he served in the Ministry of Supply and was Principal Scientific Officer at the Armament Research Department, Fort Halstead. He has carried out much experimental work on the kinetics and mechanism of chemical reaction and is author of 'The Chemistry of High Polymers'.

G. F. J. GARLICK,

Ph.D., D.Sc., F.Inst.P.,

Was born in 1919 and was educated at Wednesbury High School and at the University of Birmingham. During the war of 1939–45 he was concerned with the development of cathode-ray tubes for radar. Later he was appointed lecturer in physics in the University of Birmingham, and was there in charge of the luminescence research laboratory. He has lately been appointed professor of physics in the University of Hull. Is the author of numerous papers on luminescence and of 'Luminescent Materials' (1949).

E. B. FORD,

M.A., D.Sc., F.R.S.,

Is Reader in Genetics and Director of the Genetic Laboratories at Oxford. He has researched especially on the genetics of natural populations, and on the experimental study of evolution by a combination of ecological and laboratory methods. In this work he has made considerable use of the Lepidoptera (butterflies and moths). He has, in addition, worked on the chemistry of their wing pigments in relation to classification. He has devoted much attention to polymorphic characters and their special evolutionary properties; he was the first to treat the human blood groups as examples of polymorphism. For scientific and other purposes he has travelled extensively in Europe, the Near and the Far East, Australia, New Zealand, and the United States.

V. E. COSSLETT,

M.A., M.Sc., Ph.D.,

Was born in 1908 and was educated at Cirencester Grammar School and the University of Bristol. After periods of research in Berlin and Bristol he became lecturer in physics at Faraday House Electrical Engineering College, London, at the same time doing research at Birkbeck College. In 1939 he was appointed Keddey Fletcher-Warr Research Student of London University and during the last war became temporary lecturer in the Electrical Laboratory, Oxford. In 1946 he went to Cambridge as an I.C.I. Fellow and three years later was appointed to his present position as University Lecturer in Physics. In all these appointments his primary interest has been in electron optics, on which he has published several books and a large number of papers.

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Editor: TREVOR I. WILLIAMS, M.A., B.Sc., D.Phil., F.R.I.C.
Foreign Editor: J. A. WILCKEN, B.Sc., Ph.D.

Imperial Chemical Industries Limited, Millbank, London, S.W.1
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Organization in research

There are many indications that science is developing so rapidly that it is in danger of being retarded by its own weight unless drastic action is taken. It is, for example, no uncommon experience to find that simply through lack of material resources promising fields revealed by some new discovery can be explored only slowly or not at all. The volume of publication is now so great that for even the comparatively narrow specialist it is often difficult, if not impossible, to find time to read all that usefully pertains to his own subject. With new scientific journals constantly being established, existing ones increasing in size, and the output of books growing daily, it is certain that the problem of utilizing the literature will become even more serious unless there is some systematization of knowledge far in excess of anything hitherto considered. When new knowledge is accumulating faster than it can be mentally assimilated even by those within whose immediate field it lies, it is not surprising that its useful application is still further in arrears, for as a general rule the translation of a useful idea into a workable industrial process is long and laborious, entailing much additional research. There is some truth in the often heard assertion that if all pure research were stopped today, we should still have ample ideas to develop for many years to come.

The question of the ultimate limits of knowledge—what the human brain can grasp and what is beyond its capacity—is one of no immediate practical importance, since any such limits seem to lie well beyond our present boundaries. But in present circumstances, when the whole future of our material civilization is so intimately bound up with science and its useful application, one aspect of this question is of the utmost importance. How, with our limited resources, can the extension of our knowledge by research, both pure and applied, be effectively speeded up?

Here a major factor is clearly lack of scientific manpower, which is causing grave concern. Although urgent steps to increase it are being taken in many countries, there must be a natural limit to the expansion possible, for neither is there unlimited talent available nor is it possible, without far-reaching disturbance of national life, to divert more than a fraction of a country's manpower into scientific and technical channels. If we cannot indefinitely increase our scientific and technical manpower we must take steps to see that those available are more productive. In many sections of industry this proposition has already been accepted and put into practice, although it is only quite recently that the general public has become aware of the process—which promises to deserve the title of industrial revolution—and has begun to express concern about its social and economic consequences.

The Industrial Revolution which began in Britain in the eighteenth century is inappropriately named, for it implies a violent process which in reality never took place. Although profound and far-reaching changes occurred, they took place fairly gradually and without acute social upheaval. Even the advent of mass-production methods on the assembly-line principle—which many saw as the harbingers of mass unemployment—brought no acute difficulties, for it soon became clear that far from reducing the need for labour they in fact stimulated demand for it.

Now, two centuries later, we seem already to be in the first stages of a second industrial revolution, comparable with the first in both its importance and gradualness. As the first led to the elimination of much heavy manual toil in industry, so the second will eliminate much mental drudgery. This process is commonly known as automation, but at present the term is rather loosely applied. Frequently it is taken to imply no more than an intensive mechanization of repetitive industrial operations, in which devices incorporated within the machines themselves automatically compensate for departures from the desired performance. But many regard this kind of automatic mechanization as merely a manifestation of automation, which in its fullest sense is taken to mean the organization of highly complex work in such a way that it can be carried out by relatively unskilled workers.

The process is commonly regarded as being primarily of industrial significance, and there has been comparatively little consideration of how it might assist science. But this child of science seems well adapted to help its parent in its present problems, for these are in many respects comparable with those of modern industry. Both science and industry labour under a common difficulty: they have highly complicated operations to perform but, for both practical and economic reasons, insufficient technical manpower to carry them out by present methods. Both can ease their burden and extend their activities either by assigning more and more of their routine operations to automatic devices or by breaking their work down into simple steps which can each be undertaken by workers who have had only a little training.

Almost every well equipped laboratory can now furnish examples of the mechanization of complex operations. Such examples as self-recording infrared spectroscopes, automatic balances, chromatographic fraction-cutters, and automatic particle-counters come at once to mind. Devices such as these are, of course, doubly useful. On the one hand they save a great deal of time, and this can be devoted to more original work. On the other, they may make possible the undertaking of projects which although theoretically feasible are by ordinary methods too laborious to be embarked upon at all. For example, much of the recent progress in protein chemistry undoubtedly stems from the fact that paper chromatography has in effect provided, by comparison with the methods previously available, a method of mass-producing accurate and complete analyses of amino acid mixtures. Again, the recent rapid progress in X-ray crystallography—where there have been spectacular determinations of the structures of some very large molecules—has to a considerable extent resulted from the rapid analysis by automatic computing machines of the great quantity of data collected. Although in the important field of extracting information from the vast mass of scientific literature the methods of half a century ago still prevail, some progress towards mechanization has been made, and experiments with electronic translating machines have shown promise.

This kind of procedure seems capable of much extension, and a most interesting example is described in an article on the bubble chamber which is published elsewhere in this issue. The high pulse rate of some modern particle accelerators could have been stultified by purely practical difficulties, for data accumulated in a single day would take a year to analyse by existing methods, which demand the full attention of a skilled worker. But by means of a device in which the tracks revealed in a photograph are followed on a screen by crossed hairs, and the resulting movements are analysed by an information computer, the significant features of any collision can be determined in about a minute. This work can be carried out by an operator who has had little training, and the expert need give his attention only to those collisions which have been shown to possess points of interest.

Some scientists, and especially those brought up in an older tradition, view these changes with concern, and certainly their extensive introduction demands most careful consideration. Increasing use of apparatus whose primary function is rapidly to increase our factual knowledge may lead to a feeling that in science it is facts, rather than the principles which they enable us to formulate, that are of fundamental importance. It is true, too, that such apparatus has only limited powers of interpretation, and it is difficult to see how it could be made to take proper note of the exceptional, or even accidental, results from which great discoveries have so often stemmed. Again, it is argued that undue dependence on automatic devices may impair that manual dexterity which is so valuable a part of the equipment of the experimental scientist. Such misgivings are understandable, but it would be illogical to suppose that the immense developments which have taken place in science in recent years—which have completely changed its place in society—could be sustained without some radical changes in technique. It would be surprising indeed if methods appropriate for the conditions of half a century ago needed no revision now. Moreover, the relative importance of such considerations can be over-estimated, for the primary function of such innovations is not to reduce the scientist's working hours, but to enable him to devote a larger proportion of his time to original work, both practical and theoretical, for which his knowledge and training are essential. It is important to note that such devices would do nothing to diminish the rigour of scientific argument—which is vital to healthy progress—for their purpose is to collect information and not to interpret it.

If this argument is accepted it follows that there is strong reason for introducing automation into science with the same deliberate intent as in industry, but such a positive policy is not so far being widely followed. It is nevertheless worth noting that such a development offers one means of alleviating effectively the present grave shortage of scientific and technical manpower. It is widely prophesied that in the next half-century industrial leadership will pass to the nations which first realize and apply all the implications of automation. But today industry cannot flourish without science, and it may well be that the introduction of new methods of organizing scientific work is no less important than that of new methods of organizing industrial production.

Muscular contraction

H. E. HUXLEY

In recent years there have been considerable advances in our knowledge and understanding of the mechanism of muscular contraction. These have come from two main sources—from biophysical and biochemical studies of purified muscle proteins and of 'model' muscle systems of various types, and from investigations of the molecular structure of muscle and the changes in that structure which occur during contraction. The large-scale physiological properties of muscle are now beginning to find expression in structural and chemical terms.

Muscle may be considered as essentially a highly specialized machine, constructed from organic materials, which utilizes chemically stored energy and performs mechanical work. The existence of some such mechanism is indispensable to the directed movement of any biological system, and its speed and efficiency decisively influence the types of animal life which can exist. All machines arouse our curiosity, and this one is no exception; the question of how it works comes at once into our minds. This article will not answer this question, but it will attempt to summarize some of the evidence and arguments on which our present ideas about muscular contraction are based. These ideas, though fruitful in many respects, have one very great failing: they have not enabled us to decide what fundamental principle or property is involved in contraction. Non-biologists may be surprised that such an unsatisfactory state of affairs should prevail in so important a subject, but, in fact, our knowledge and understanding of muscle are probably more complete than they are of any other biological system. If the mystery of contraction remains unsolved for long, it will not be for want of experiment or thought.

GENERAL PROPERTIES OF MUSCLE

There are basically two different types of muscle. Voluntary muscles are quick-acting and exhibit a banded or striated appearance in the light microscope; this class includes the skeletal muscles used to produce body and limb movements in vertebrates. Involuntary muscles, such as those which produce intestinal movements, or the dilatation of the capillaries, are in general much slower in their operation, and they do not appear banded. The two types are usually referred to as 'striated' and 'smooth' muscles respectively. Cardiac muscle seems to occupy an intermediate position, for although not under voluntary control, its structure resembles that of striated muscle. The properties of smooth muscle have been studied a good deal less than those of striated muscle, and it is with the latter that we shall mainly be concerned.

A whole muscle is built up of a large number of individual fibres, which range in diameter from 0·01 to 0·1 mm and which may extend the whole length of the muscle. These fibres are electrically excitable, and they will contract when an electrical impulse is transmitted to them down the motor nerve. A single impulse produces a single contractile event, known as a twitch, whose duration is of the general order of magnitude of one-tenth of a second, though considerable variation exists between different muscles. A longer contraction, known as a tetanus, can be maintained by a continuous flow of impulses. When the impulses cease, contraction ceases too, and if the muscle has been allowed to shorten it may be re-extended by a very small force. The muscle is said to relax. Under normal physiological conditions muscles do not in general shorten to below 65 per cent of their resting length, nor stretch to more than about 140 per cent of their resting length. The normal range of operation is often even more restricted than this: 85 per cent to 120 per cent would be a typical figure. The tension exerted by a muscle is a maximum at resting length and decreases on either side of that length.

During a tetanus, a muscle can exert a tension of about 4–5 kg per square centimetre of its cross-section. The tension exerted is a function of the velocity of shortening [1]. Maximum tension is exerted when the muscle is not allowed to shorten at all, i.e. during an isometric contraction. If P_0 is the maximum tension that the muscle can exert at any particular length, then when it is shortening with velocity v the tension exerted will be P, where $(P + a)v = (P_0 - P)b$, a and b being constants for a given muscle. This is the well-known Hill equation. One feels that such a simple relationship must reflect some very simple feature of the mechanism of contraction.

HEAT PRODUCTION

When one considers the production of heat by a contracting muscle, the above relationship takes on an even simpler form. The heat given out by a muscle during contraction may conveniently be divided into two parts: the initial heat, which always appears, whether the muscle is allowed to shorten or not; and the shortening heat, which appears when the muscle decreases in length [2]. No heat changes take place when the muscle relaxes and returns to its resting length. The amount of shortening heat is proportional to the distance the muscle shortens, and is independent of the tension being exerted during the shortening process. Moreover, the heat evolved for an amount of shortening x is found to be equal to ax, where the constant a has the same value as it does in the force-velocity equation. Thus, leaving aside the initial heat, the left-hand side of the force-velocity equation given above will represent the total rate of energy release (heat + work) by the contracting muscle. The equation therefore shows that this quantity is proportional to the difference between the maximum tension and the tension which is actually being exerted. This seems to be a very significant relationship.

ENERGY RELEASE

The fact that the amount of heat produced when a muscle shortens by a given distance is independent of the external work done by the muscle is most remarkable. A good many of the more straightforward mechanisms that might be suggested for contraction set free a constant total amount of energy when they shorten a given distance, and they would therefore predict a heat of shortening which increased as the external work decreased. But in muscle the total energy released in a given distance varies with the load, and it is always equal to the external work done plus a constant shortening heat. Moreover, this is an inherent property of the contractile material, and is not dependent on some feedback arrangement in the nervous system. In some respects the system resembles an electric motor drawing a larger current from the mains supply when its speed is decreased by an external load, though this analogy cannot be pursued very far.

The mechanism of contraction must clearly be of a very special kind. First of all, the chemical reaction which releases energy for contraction must be linked to a movement or change of shape in the molecular structure of the muscle. Secondly, this movement or change of shape must enable the muscle as a whole to shorten by at least one-third of its resting length. Thirdly, the amount of reaction which takes place must be determined by the external work done by the muscle and not by the distance it shortens. Fourthly, the mechanism must give the very simple force-velocity relation described by the Hill equation. Fifthly, after a contraction the muscle must be able to return to its resting length without any further heat changes taking place. Thus, even apart from its relevance to muscular contraction, it is of considerable intrinsic interest to try to discover how such a molecular mechanism can work.

APPROACHES TO THE PROBLEM

The properties of muscle which have been briefly outlined above are so striking and so clearly defined that one feels they ought to be explicable in fairly simple terms. An explanation can be sought in two rather different ways. The first approach is simply to try to see how a muscle is constructed. The large-scale structures can be studied in the light microscope; the details of the fine structure can be observed in the electron microscope or investigated by X-ray diffraction techniques. If the structure of the working parts of a muscle can be described in sufficient detail, then one should be very close to understanding how the mechanism operates.

The second approach is the biochemical one. Many of the components of a muscle can be extracted and purified, and their chemical and physical properties studied either individually or in combination with one or more other components. Systems can be set up—for instance, artificial fibres prepared from purified muscle proteins—which display some of the properties of living muscle, and whose behaviour can be studied under much more closely controlled conditions.

The two approaches can never be wholly separate, nor should they be; they differ much more in the way the information is obtained than in the type of information they ultimately seek. The correlation of the information obtained by the different methods not only helps to preserve an atmosphere of realism in the different disciplines but should eventually remove the boundaries between them, so that the same phenomena might equally well be described by a physiologist, a biochemist, or a physicist, each using terms which have a real meaning to the others. Before discussing the

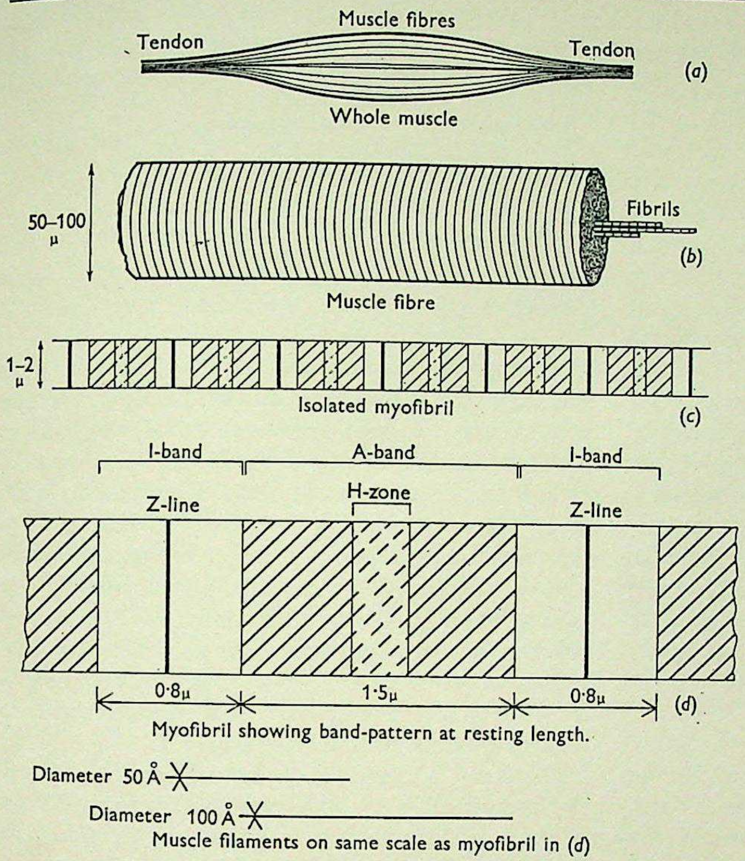

FIGURE 1 – *The structure of muscle at different levels of organization; dimensions shown are those for rabbit psoas muscle.*

contractile structure itself, however, brief mention should be made of the means by which the signal for contraction is transmitted into that structure.

MECHANISM OF STIMULATION

The muscle fibre is the smallest unit which will perform a normal physiological contraction. Each fibre is surrounded by a thin membrane which is electrically polarized and in the resting state has a potential difference of about one-tenth of a volt across it, the inside being negative. When the muscle is stimulated, via its motor nerve and motor end-plate, a wave of depolarization, the action potential, travels down the muscle membrane, with the result that the potential difference across it falls to zero and, in fact, overswings and reverses in sign. Almost immediately the muscle contracts. The depolarization of the membrane is known to alter its permeability to different ions, and it is natural to inquire whether the passage of some specific ion through the external membrane could trigger off the contraction. However, such an explanation is not tenable, at least in its simple form, for the muscle fibre becomes fully active across its entire cross-section in a much shorter time than such ions would take to diffuse to or from the centre of the fibre [3]. Recently it has been suggested [4] that the signal for contraction might be transmitted into the interior of the fibre at the requisite speed as a wave of depolarization in an internal transverse membrane. A system of such transverse membranes, spaced at short intervals along the fibre, and each releasing activator in the interior of the fibre when they were depolarized, would then provide the necessary speed of activation. Strong evidence has been produced [4] that such a mechanism does in fact exist in striated muscle.

THE CONTRACTILE STRUCTURE

The contractile material is located inside the muscle fibres in the form of thin longitudinal fibrils, called myofibrils, about 1 micron in diameter, packed close together across the width of the fibre and extending along its whole length. If the fibres are disrupted mechanically, for instance in a Waring blender, the individual fibrils are released. These isolated myofibrils provide a very important experimental material. Though they cannot, of course, be stimulated electrically, they can be made to contract by appropriate biochemical treatments; they seem to contain the essential contractile apparatus of muscle, still in a highly organized form, but free from the complicated and uncontrollable factors present in a whole living muscle.

The fibres of voluntary muscle are crossed by a regularly repeating pattern of bands; these cross-striations have a periodicity of the order of two or three microns at resting length. The period seems to be constant for a given type of muscle at resting length, but varies somewhat from one type of muscle to another; some muscles (e.g. the leg muscles of certain spiders) have exceptionally long striations. This banding is a property of the myofibrils, which are arranged in the fibre with their striations in register. The pattern is shown in figure 1, and figure 3(*a*) (page 185) shows an individual myofibril photographed in phase-contrast illumination. The principal feature is the succession of alternating dark and light bands, which correspond to dense and less dense regions of the myofibril. The dense bands are birefringent and are known as the A (anisotropic) bands; the less dense bands are relatively non-birefringent and are known as the I (isotropic) bands. The I-bands are bisected by a dense line, known as the Z-line or Z-membrane. The Z-membranes appear to be continuous across the whole width of the fibre and to hold the fibrils in register; there is evidence [4] that they may provide the path along which the signal for contraction is transmitted into the interior of the fibre.

This pattern has been described in some detail, for its features are not of merely morphological interest: they are the visible expression of the highly organized molecular structure responsible for contraction; they are related to that structure in a remarkably simple way; and once that relationship has been recognized they can give very specific information about the nature of the molecular changes taking place during contraction.

STRUCTURE VISIBLE IN THE ELECTRON MICROSCOPE

When muscle is examined in the electron microscope it is found that the myofibrils themselves are built up of smaller longitudinal filaments having diameters of the order of 100 Å. These filaments remain straight when the muscle contracts. They form a continuous array across the whole width of the myofibrils, being spaced out a few hundred Ångström units apart; in life, the space between them is filled with a solution of salts and soluble proteins. The array of filaments is quite crystalline in its regularity, and living muscle will reflect X-rays quite strongly at the appropriate angles [5].

Within the last few years, technical developments have made it possible to cut sections of muscle and other biological tissues which are sufficiently thin to be examined in the electron microscope. This has greatly extended the range of usefulness of the instrument, and, because of the extreme thinness of the sections (only one or two hundred Ångström units), has made it possible to achieve resolution of the order of 30 Å on biological material. Examination of electron micrographs of very thin cross-sections of muscle reveals some remarkable features about the structure [6]. Cross-sections through the denser parts of the A-band (i.e. the regions on either side of the H-zone) show that two different types of filaments are present here (figure 4(*a*–*e*)). First there is a hexagonal array of 'primary' filaments about 100 Å in diameter and spaced about 200–300 Å apart. The spacing as measured by X-ray diffraction in living muscle is 450 Å, and the lower value seen here is probably due to shrinkage during the preparation of the material for sectioning. Between the primary filaments a secondary array of thinner filaments, about 40–50 Å in diameter, can be seen; each secondary filament lies symmetrically between three primary filaments, so that each primary filament has around it six secondary filaments which it shares with its six nearest neighbour primary filaments. The arrangement is shown diagrammatically in figure 2.

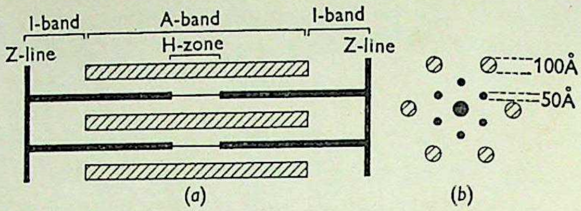

FIGURE 2 – *Diagrammatic representation of arrangement of filaments in striated muscle:* (a) *longitudinal,* (b) *sectional.*

Sections through the central region of the A-band, the H-zone, show only the hexagonal array of primary filaments (see figure 4(*f*)), and any secondary filaments in this region must be so thin as to escape detection. Sections through the I-band show only thin filaments of diameter about 50 Å, and the hexagonal array of primary filaments is not present in this band, as indeed is obvious from longitudinal sections (see figure 3(*b*)).

The conclusion from these observations is a very straightforward one. It is simply that the fibrils are built up of two overlapping, interpenetrating arrays of longitudinal filaments (figure 2). The thick filaments are confined to the A-band and produce the high density and birefringence of that band. Thin filaments extend in either direction from the Z-line, through the I-band, into the A-band, and terminate or become much thinner at the edge of the H-zone. The densest zone of the band pattern occurs where the two arrays of filaments overlap, i.e. in the region of the A-band on either side of the H-zone. The next densest zone occurs where the thicker filaments are present on their own, i.e. in the H-zone. The least dense band occurs where thin filaments alone are present, i.e. in the I-band, for although there are twice as many of them as there are thick filaments, the cross-sectional area of each one of them is only about one quarter as great.

We see then that the visible striated appearance of skeletal muscle arises directly from the organization of the contractile material of the myofibrils into two distinct, overlapping arrays of filaments.

BAND PATTERN CHANGES DURING CONTRACTION AND STRETCH

The A- and I-bands have lengths of the order of one micron. Thus in the physiological range of contraction the changes in band length can be only fractions of a micron. Such small changes are difficult to measure, particularly when they are taking place very rapidly, and the measurements are very susceptible to optical artifact. Fixing the muscle prior to examination in the light microscope or the electron microscope does not really solve the problem, for the fixation process may itself introduce changes in band length. It is only in the last few years, with the introduction of the phase-contrast and interference microscopes, that accurate and dependable measurements have become technically possible [7, 8]. The results are remarkably simple. Consider, for example, skeletal muscle from the rabbit or the frog. At resting length, the distance between successive Z-lines, which defines the repeating period of the cross-striations, is 2·3 microns; the length of the A-band is 1·5 microns and that of the I-band 0·8 micron. When the muscle contracts, the A-band remains at constant length, and the I-band decreases in length until it disappears altogether at about 65 per cent of the resting length. This is the normal limit of physiological contraction, and further shortening beyond this point produces dense contraction bands where adjacent A-bands have been brought into contact at the Z-line. In figures 6 and 9 these changes are illustrated both diagrammatically and as they take place in a single muscle fibril observed in the phase-contrast microscope.

If relaxed muscle is stretched, the A-bands remain at constant length and the increase in length is taken up by the I-bands. During contraction from a stretched condition the same process happens in reverse. During an isometric contraction, when the muscle exerts a force but is not allowed to shorten, neither the A- nor the I-bands change in length. It appears that under all conditions the band pattern is determined simply by the length of the muscle, and is the same whether the muscle is in the active state or not. Moreover, the same band pattern changes are observed in experiments both on living fibres contracting under normal physiological conditions and on isolated fibrils made to contract by biochemical means.

One further, and most illuminating, feature of the band-pattern changes should now be described. It will be recalled that the central region of the A-band, the H-zone, is somewhat less dense than the regions on either side of it. When the muscle increases in length, the H-zone increases in length by the same amount, although the total length of the A-band remains constant. Thus the distance from the Z-line to the edge of the H-zone remains constant (see figure 8). The appearance of a stretched fibril, with its very long H-zone, is shown in the electron micrograph reproduced in figure 7. During shortening, the H-zone decreases in length until it disappears at about 85 per cent of the resting length; it is replaced by a dark line if further shortening occurs.

These observations have a very simple explanation, which becomes particularly obvious when the electron microscope observations are kept in mind. It is that the two arrays of filaments, whose lengths define the length of the A-band and the distance from the Z-line to the edge of the H-zone, always remain, so far as possible, at constant length, and that changes in the length of the muscle are brought about simply by the two arrays sliding into or out of each other [7, 8]. If the muscle contracts too far, the filaments of one or of both arrays will have to crumple up at the ends for steric reasons, but over a considerable range of lengths the sliding process alone takes place. Additional support for this hypothesis is provided by the X-ray diffraction data.

X-RAY DIFFRACTION EVIDENCE

The filaments seen in electron micrographs of muscle often show a longitudinal periodicity of about 400 Å, and a similar axial period (415 Å) has been demonstrated in low-angle X-ray diffraction diagrams obtained from living muscle [5]. The X-ray reflections are very sharp and show that the periodicity must be maintained with almost atomic precision. When a living muscle is stretched, the X-ray period does not increase, and diagrams obtained from artificially contracted muscle suggest that the period remains constant there too. It is not clear at present whether the X-ray period arises from the internal structure of only one type of filament or of both types. However, whichever is the case, the X-ray evidence shows that the structure which gives rise to the 415 Å axial period does not change in length when the muscle changes in length. This result is in perfect accord with a sliding-filament model.

No characteristic changes associated with contractions have been observed in the wide-angle

X-ray diagram given by muscle [9]. This again shows that the major part of the internal structure of the filaments retains a constant atomic configuration during contraction.

From the light microscope and electron microscope evidence, and from the X-ray data, the conclusion seems inescapable that contraction is brought about by some mechanism which causes the two different types of filament to slide past each other. We must now inquire what is the composition of these filaments, and what interactions between them might cause such a sliding process to occur.

THE PROTEIN COMPONENTS OF MUSCLE

Muscles contain about 20 per cent of protein and 80 per cent of dilute salt solution. About two-thirds of the protein is present in fibrous form and constitutes the contractile structure of the muscle. Other proteins present include enzymes for facilitating reactions which convert the energy-rich compound glycogen from the bloodstream into another compound which can be used directly as an energy source by the contractile machinery. These metabolic reactions synthesize adenosine triphosphate (ATP), and it has long been realized that the hydrolysis of this compound to adenosine diphosphate (ADP) was a reaction very closely linked to the contractile process. Although this reaction can be demonstrated as taking place in contractions of appreciable duration, attempts to demonstrate any breakdown of ATP during a single twitch have not been successful [10, 11]. It remains in doubt, therefore, whether some other compound, itself synthesized from ATP, might not be the immediate energy source, or even whether the contractile mechanism might not itself be able to perform one twitch without an external supply of energy.

The two great simplifying discoveries in muscle biochemistry which have enabled thought and experiment to be directed at the real essentials of the problem of contractility are concerned with the structural proteins. Two of these, actin and myosin, are of special importance and together make up about half the total protein in muscle. Myosin had for a very long time been recognized as a typical fibrous protein, and it was generally believed that some change in the configuration of the myosin molecule was the factor responsible for muscular contraction. It was a considerable sensation, therefore, when the discovery was made [12] that myosin is itself the enzyme which catalyses the breakdown of ATP to ADP.

Perhaps even more dramatic still was the discovery that artificial fibres made from a mixture of actin and myosin extracted from muscle will contract when they are placed in a suitable solution containing ATP [13, 14]. These discoveries showed that the entire basic mechanism of contractility is contained in the actin-myosin-ATP system.

PROPERTIES OF MYOSIN AND ACTIN

Myosin has a molecular weight often reported to be 800,000 (see, for example, [15]), but is now reported as being only half that value [16]. The molecule is long and thin, and light-scattering and other measurements [15, 17] give a length in the range 1500–2000 Å, with a diameter of about 20 Å. Actin has a molecular weight of about 70,000 [15], but its shape is uncertain. It can exist in solution in two different forms. One form is known as globular or G-actin, and seems to consist of either single molecules or dimers. When salt is added to solutions of G-actin, another form, known as fibrous or F-actin, is produced. One might therefore expect the actin in muscle to be present as F-actin. Solutions of F-actin have a high and anomalous viscosity, exhibit strong flow-birefringence, develop birefringence spontaneously on standing, and display many other characteristics to be expected of long polymers of G-actin units. They have two very interesting features. If actin is labelled with a fluorescent dye, then the rotational periods of the G-actin units in F-actin can be calculated from measurements of the depolarization of fluorescent radiation. These measurements lead to the conclusion that the G-actin units in fibrous actin have freedom of rotation about at least one axis [18]. It is also found that globular actin has ATP bound to it, and that the ATP is transformed into ADP when G-actin polymerizes to form F-actin [19].

When solutions of actin and myosin are mixed together, the viscosity of the mixture is considerably higher than the sum of the viscosities of the constituents. If the mixture is centrifuged at high speed, almost all the protein forms a compact pellet of sediment, whereas under similar conditions myosin on its own would remain largely in the supernatant [20]. It is clear that some sort of complex can form between actin and myosin; this is known as actomyosin. If ATP is added to a solution of actomyosin in 0·6 M. KCl, a large fall in viscosity occurs, and myosin, and only myosin, can be recovered from the supernatant left after a degree of centrifuging that would bring down actomyosin and F-actin [20]. It seems, then, that at this salt concentration, ATP dissociates the actomyosin complex into actin and myosin; ATP is itself split by myosin, and when all the ATP has been hydrolysed in this way the actomyosin complex reforms. At lower salt concentration (e.g. 0·1 M.) ATP brings about the precipitation of actomyosin from solution. And when the actomyosin has been orientated into threads, ATP produces contraction.

If the actin molecules are labelled, as before, with a fluorescent dye, they will still form actomyosin; fluorescence depolarization measurements show that the actin units in actomyosin behave as monomers having freedom of rotation about at least one axis; when actomyosin is dissociated by ATP, the actin immediately behaves as though it were composed of dimers [21]. These are all fascinating and rather baffling relationships, and no comprehensive scheme that will explain all of them has yet been evolved.

MODEL SYSTEMS

The inter-reaction between actin, myosin, and ATP can also very profitably be studied in model systems which lie in their complexity part-way between the purified protein solution and the living fibre. The first of these, the actomyosin thread, has already been mentioned. The second is the so-called glycerol-extracted fibre model. It was found by Szent-Györgyi [22] that muscle fibres which had been kept cold in 50 per cent glycerol for a few days or weeks would, though of course no longer electrically excitable, contract when placed in suitable solutions containing ATP. It has been found that this contraction imitates in very many respects the contraction of a living fibre, although it takes place more slowly. The maximum tension exerted is roughly the same.

The glycerinated fibres are normally inextensible and resemble muscle in rigor, for they have lost the ATP which fresh, living muscles contain. If, after an ATP-induced contraction, the ATP is washed out of such a fibre model, then the fibre 'sets' at the shortened length. If, however, the dephosphorylation of ATP is inhibited either by an enzyme poison, for instance salyrgan, or by a factor [23] which can be extracted from fresh muscle, then not only is contraction abolished, but the fibre may now be readily re-extended to its original length. Under these conditions ATP is said to act as a plasticizer.

Certain inorganic phosphates, as for instance sodium pyrophosphate [24], also produce a plasticizing effect on glycerinated muscle; these compounds are not dephosphorylated by myosin, but they all have the property of lowering the viscosity of an actomyosin solution; so, like ATP, they can presumably dissociate the actomyosin complex.

These observations may be compared with the behaviour of living muscle fibres. These contain ATP, but in the resting state the enzymatic activity of myosin is inhibited in some way and ATP breakdown is very slow; the fibres are quite flexible and may be stretched easily. During contraction the muscle becomes quite rigid, but regains its plasticity when the contraction is over. If the muscle is allowed to pass into rigor, a condition associated with the loss of ATP, then the fibres will no longer contract, and they become rigid and inextensible.

It seems, then, that ATP performs a dual role in muscle. When dephosphorylation cannot take place, the presence of ATP keeps the muscle plastic and extensible; when dephosphorylation can take place, the presence of ATP causes contraction.

BIOCHEMICAL CONCLUSIONS

We may summarize the biochemical evidence as follows:

1. The contractile structure is built largely out of two proteins, actin and myosin.
2. Some sort of combination can occur between actin and myosin.
3. This combination is modified by the presence of ATP.
4. Myosin is an enzyme for the dephosphorylation of ATP.
5. The dephosphorylation of ATP is very closely linked with the release of energy for contraction.
6. The presence of ATP without dephosphorylation makes the contractile structure extensible.
7. Other substances which, like ATP, dissociate actomyosin, also make the contractile structure extensible.
8. In the absence of ATP or other plasticizer the contractile structure becomes rigid and inextensible.

Let us now see what expression these concepts find in our structural knowledge of muscle.

THE PROTEIN COMPOSITION OF THE FILAMENTS

Myosin can be dissolved out from either whole muscle or from isolated myofibrils by procedures which remove little or no actin [25]. Microscopic observations [26, 27] show that the removal of myosin is associated with the extraction of the dense material of the A-bands, i.e. of the so-called A-substance. This is illustrated in figure 5, which shows an isolated myofibril before and after myosin has been extracted from it. A 'ghost' fibril is left, consisting of material extending from the Z-lines to the edge of what was formerly the H-zone; the H-zones now have a very low density, but the fibril structure is still continuous across them. The ghost fibrils will not contract in solutions containing ATP. In the electron microscope it can be seen that the array of thick filaments which characterized the A-bands of normal muscle is no longer present. Moreover, quantitative measurements made with the interference microscope [28] show that the amount of A-substance, present in intact fibrils and removed from them when myosin is extracted, is exactly equal to the myosin content of the fibrils given by biochemical analysis. One can conclude, therefore, that the thick filaments seen in the electron microscope in the A-bands of muscle are made up very largely of myosin.

After myosin has been removed from muscle, actin can be extracted by another procedure. When the ghost fibrils remaining after myosin extraction are treated in the same way, then most of the residual material between the Z-line and the edge of the H-zone is removed (see figure 5). It will be remembered from the account of electron-microscope observations that this material consists of the thin filaments which formed the secondary hexagonal array where they overlapped with the thick filaments in the A-band. Thus one must conclude that these secondary filaments contain the protein actin.

One arrives, therefore, at the very simple concept that the two principal contractile proteins of muscle, actin and myosin, are organized into separate filaments; and that the interaction of actin and myosin filaments with ATP causes them to slide past each other (figure 10). It is in the light of this model that a relation should be sought between the biochemical observations and the physiological behaviour of muscle.

CORRELATION OF STRUCTURE, BIOCHEMISTRY, AND PHYSIOLOGY

The construction of striated muscle in this particular fashion would appear to offer two advantages from the mechanical point of view. These arise from the two basic features of the structure—the discontinuous nature of both the actin and the myosin filaments, and the fact that groups of filaments of any one type are arranged in register. In the first place, a considerable amount of shortening can take place without either type of filament having to fold up in any way. Secondly, the filaments within any given array do not move relative to each other, and so internal frictional losses will be kept at a minimum. The arrangement looks neat, efficient, and well adapted to carrying out rapid contractions [29].

A good starting point to show the way in which the different types of information about muscle are beginning to fit together is provided by the behaviour of muscle when it is stretched. During stretch we have seen that the actin filaments are drawn further out of the array of myosin filaments. If cross-links were to be formed between the actin and the myosin filaments, then, if the filaments themselves were inextensible, the muscle too would be inextensible. Such cross-links would correspond to the combination that can take place between actin and myosin in solution. ATP is believed to dissociate this combination, and one might therefore expect it to break the cross-links between actin and myosin filaments. Thus the observation that muscle and muscle models are extensible only in the presence of ATP, or of other substances which can dissociate the actomyosin complex, can be accounted for in an extremely simple way.

CONTRACTION MECHANISMS

The picture of contraction which has now emerged may be summarized as follows.

In the resting state, the two overlapping arrays of filaments are not linked to each other because of the presence of ATP and the absence of ATP breakdown. When the muscle is stimulated, the release of some activator allows the enzymatic breakdown of ATP to commence. An interaction between myosin, actin, and ATP takes place and, as a result, the array of actin filaments is drawn further into the array of myosin filaments, producing shortening of the muscle and the observed change in band pattern. When ATP breakdown ceases, its interaction with myosin and actin no longer produces contraction but simply breaks the links between the two filaments; the muscle can then be re-extended. In the case of a glycerinated fibre the process is similar, except that ATP breakdown, and contraction, begin as soon as ATP is supplied to the fibre, and finish only when ATP is washed out of the fibre, leaving it locked at its

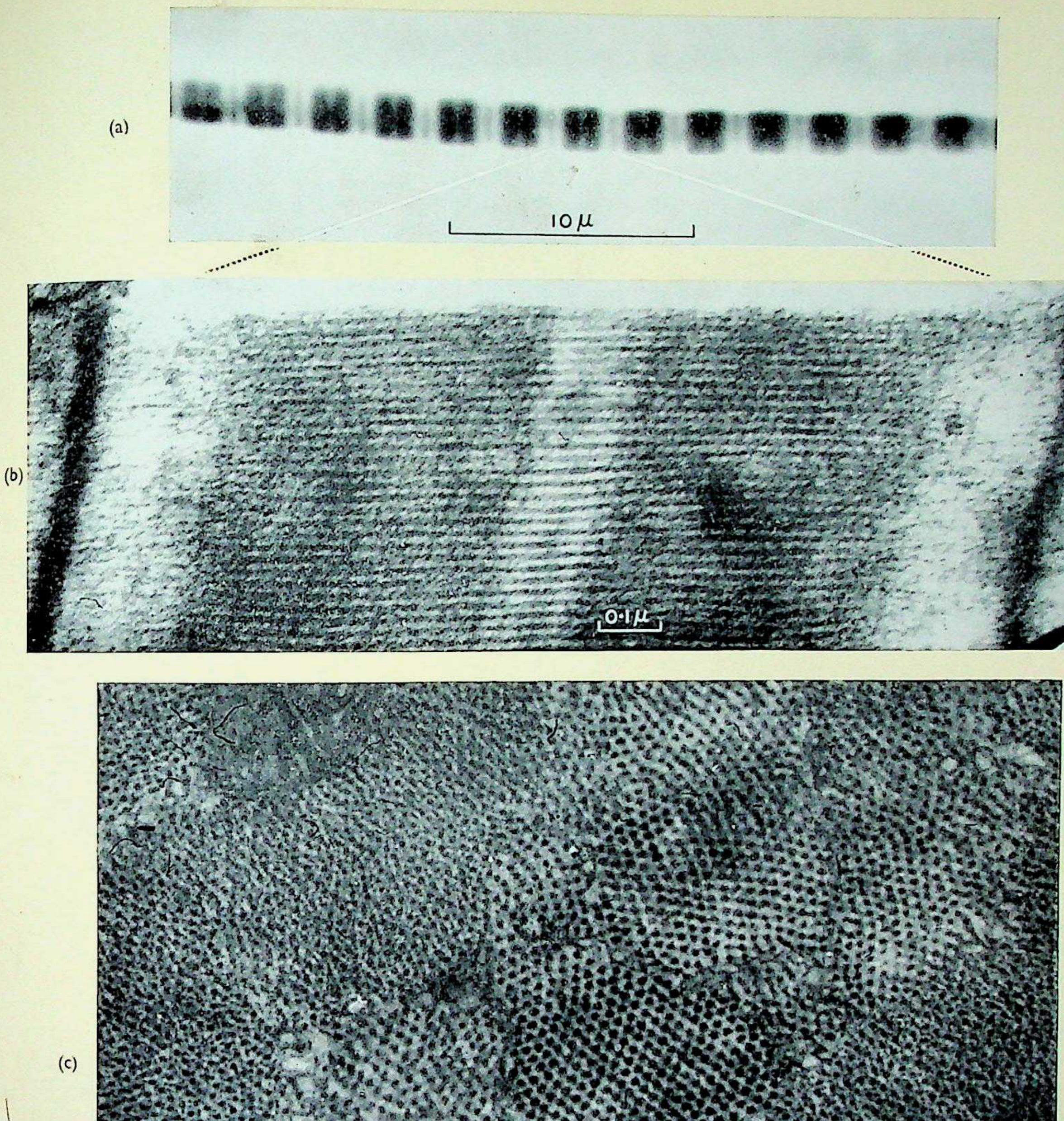

FIGURE 3 – (a) *Myofibril from rabbit psoas muscle, photographed in phase-contrast illumination. Note dense A-bands; the I-bands are less dense and are bisected by the Z-lines.* (b) *Ditto, as seen in electron microscope (longitudinal section).* (c) *Cross-section of muscle, showing the continuous array of filaments; in the centre of the picture the section has passed through an H-zone and a simple array is visible; on either side the compound array present in the rest of the A-band may be seen.* (*Magnification as* 3(b).)

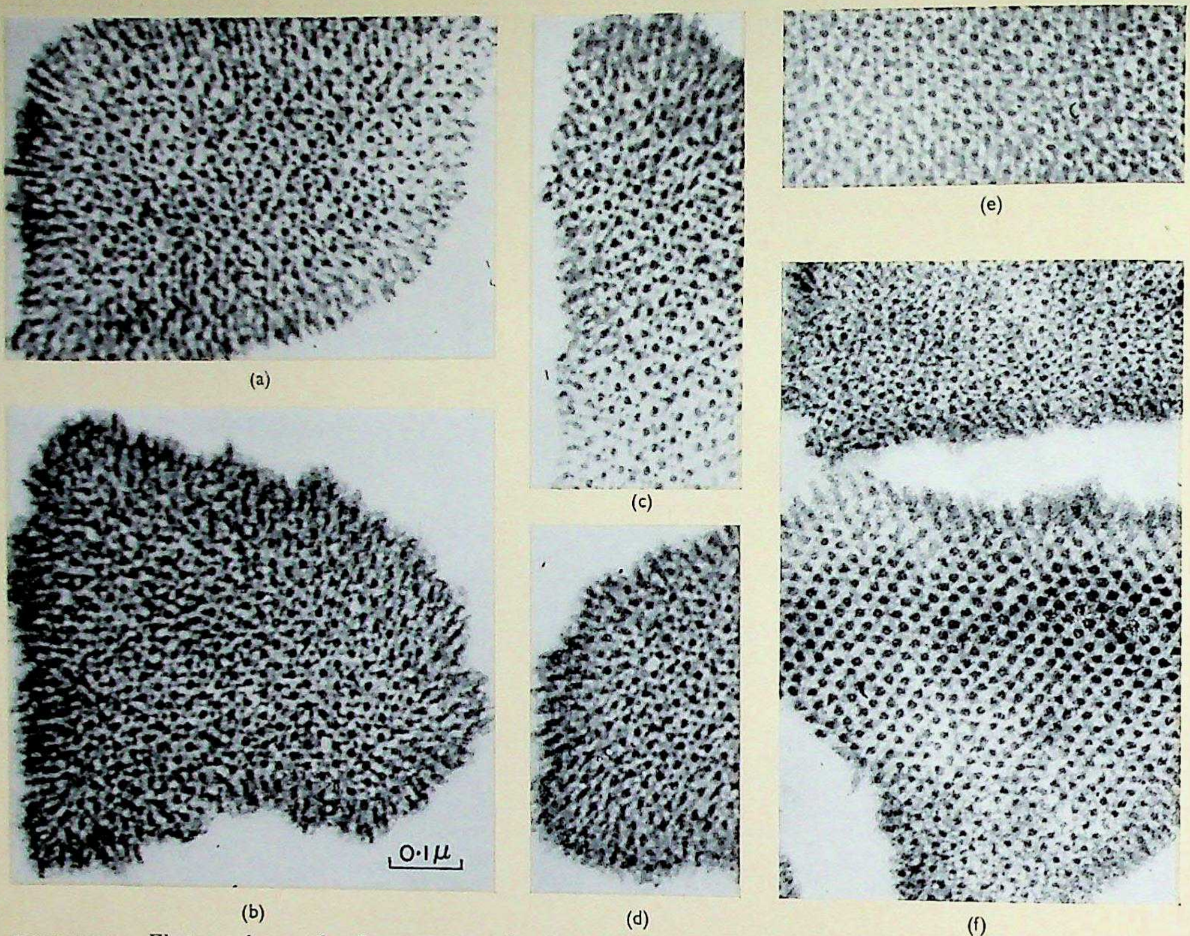

FIGURE 4 – *Electron micrographs of cross-sections of rabbit psoas muscle (stained with osmic and phosphotungstic acids). (a–e) Sections showing double hexagonal array of filaments in the A-band. (f) Sections showing simple hexagonal array of filaments in the H-zone.*

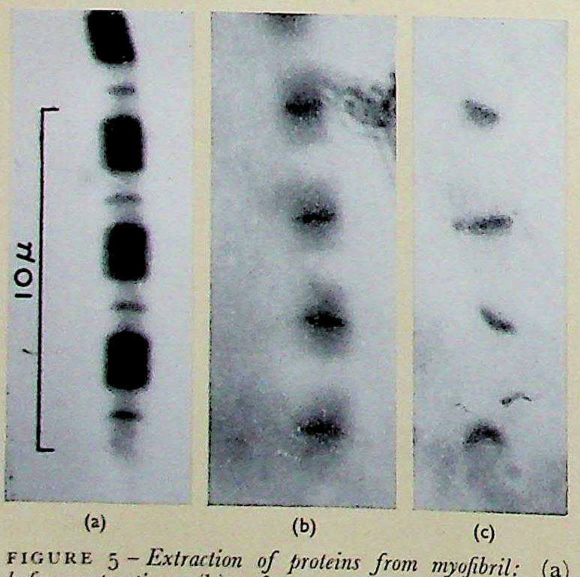

FIGURE 5 – *Extraction of proteins from myofibril:* (a) *before extraction;* (b) *after extraction of myosin (note removal of A-substance);* (c) *after extraction of actin; only Z-lines and some backbone material remain.*

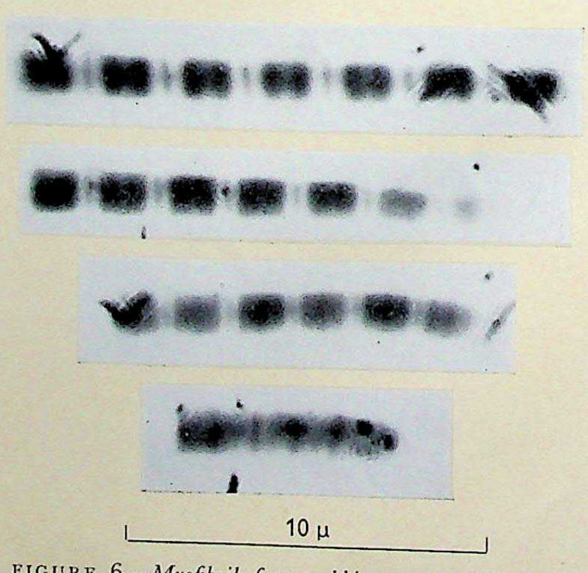

FIGURE 6 – *Myofibril from rabbit psoas muscle, photographed in phase-contrast illumination at successive stages of an ATP-induced contraction. Note shortening of I-bands and disappearance of H-zones.*

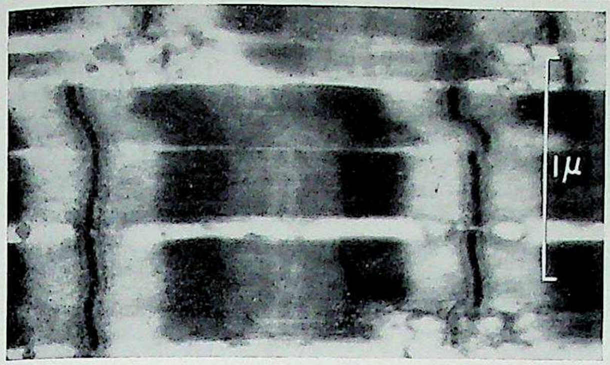

FIGURE 7 – *Electron micrograph of longitudinal section of stretched muscle; note long H-zones.*

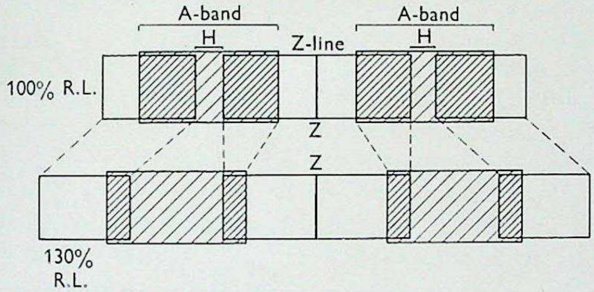

FIGURE 8 – *Diagram of band-pattern changes during muscle stretch; the distance from the Z-line to the edge of the H-zone remains constant.* R.L. = *Resting length.*

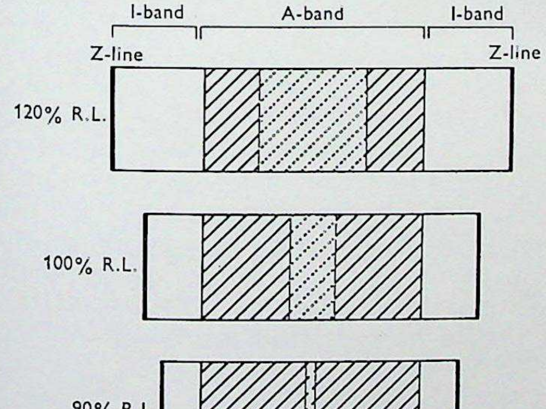

FIGURE 9 – *Diagrammatic representation of band-pattern changes during contraction.*

shortened length. The essential feature is that actin filaments are made to slide past myosin filaments by a reaction in which the dephosphorylation of ATP is involved but the details of which remain unknown. This feature sheds new light on a number of aspects of muscular contraction, which we will now consider briefly.

Each filament contains several hundred actin or myosin molecules. The X-ray diffraction evidence shows that in at least one type of filament, and perhaps in both, the molecules form a regularly repeating pattern. In the region where the two arrays of filaments overlap, myosin-actin interactions are likely to take place at a large number of points where actin and myosin molecules come into apposition. These interactions cause the two filaments to slide past each other. Each time the filaments move relative to each other by a distance equal to their axial periodicity, then virtually the same spatial pattern of interactions between them will recur. One might therefore expect the system to work in a step-by-step fashion, each complete contraction of the muscle being brought about by the repetition of a number of identical contractile events at the sites of myosin-actin interaction.

A possible mechanism could consist of obliquely oriented cross-linkages extending from the myosin molecules on one filament to the actin molecules on the other; the cross-linkages could form part of the myosin molecule itself. Shortening of the link would pull the actin filament along a short distance. The link could then be detached from the actin molecule (say by the arrival of a molecule of ATP), re-extend again, attach to the actin filament a little further along, and the whole process repeated. A more complicated mechanism involving repetitive alternations in length of the actin filaments has also been discussed.

Whatever the details of the mechanism, however, the same basic property remains: a number of minor cycles of a detailed molecular process take place within the major cycle of contraction and relaxation of the muscle itself. Thus one cannot simply equate the return of the muscle to its resting length with the re-extension of the contractile material; thus arguments about whether muscle as a whole relaxes actively or passively, though very important in many other respects, have no direct relevance to the question whether the contractile material extends actively or passively at the molecular level. Another feature of this type of mechanism is that each enzyme site—that is, each myosin molecule—can take part in the reaction a large number of times during each

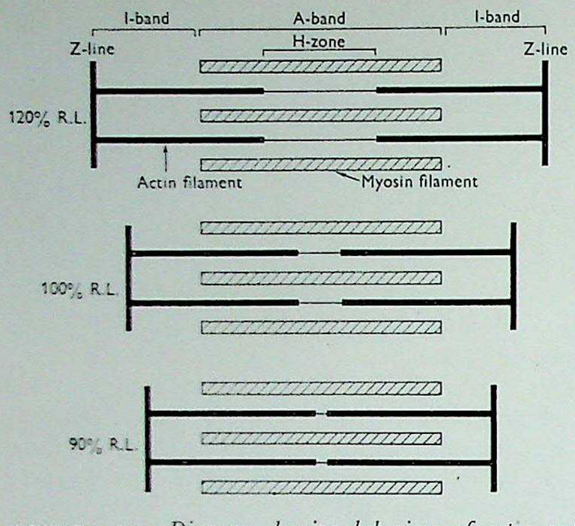

FIGURE 10 – *Diagram showing behaviour of actin and myosin filaments during changes of muscle length.*

overall contraction cycle. The total work done per cycle will therefore be much greater than in a system where each link can shorten only once per cycle, as for instance would be the case if the shortening of a number of links were added up in series.

A system of links, acting in parallel and having to break and reform each time a small amount of shortening takes place, has another interesting property. If a finite time is required for each link to form, then the number of links in existence at any particular moment, and hence the total tension exerted, will be a function of the speed of shortening. If the system is prevented from shortening, then there will be time for the maximum possible number of links to form, and the tension will be a maximum. Making a small number of assumptions, it can be shown that in such a system the rate of energy release varies with load in a manner which imitates closely the simple and striking behaviour of muscle itself [30].

The observations lead, then, to a mechanism whose general behaviour fits in very well with the physiological properties of muscle. The basic nature of this mechanism, however, still remains unknown. We still require electron micrographs which show the internal structure of the filaments and the details of any cross-connections between them; the details of the X-ray diffraction diagrams remain uninterpreted; and the actin-myosin-ATP interaction has still to be described in detailed terms. There is every hope that, along these lines, the problem of muscular contraction can be solved.

ACKNOWLEDGMENT

I am much indebted to my colleague Dr Jean Hanson; many of the ideas discussed in this article were the outcome of our collaboration, and the light-microscope photographs shown are taken from our joint publications. Many similar ideas have been developed by A. F. Huxley and R. Niedergerke.

REFERENCES

[1] Hill, A. V. *Proc. roy. Soc., B*, **126**, 136, 1938.
[2] *Idem. Ibid.*, **136**, 195, 1949.
[3] *Idem. Ibid.*, **136**, 399, 1949.
[4] Huxley, A. F. and Taylor, R. E. *J. Physiol.*, **130**, 49, 1955.
[5] Huxley, H. E. *Proc. roy. Soc., B*, **141**, 59, 1953.
[6] *Idem. Biochim. Biophys. Acta*, **12**, 387, 1953.
[7] Huxley, A. F. and Niedergerke, R. *Nature, Lond.*, **173**, 971, 1954.
[8] Huxley, H. E. and Hanson, J. *Ibid.*, **173**, 973, 1954.
[9] Astbury, W. T. *Proc. roy. Soc., B*, **134**, 303, 1947.
[10] Fleckenstein, A., Janke, J., Davies, R. E., and Krebs, H. A. *Nature, Lond.*, **174**, 1081, 1954.
[11] Mommaerts, W. F. H. M. *Ibid.*, **174**, 1083, 1954.
[12] Engelhardt, W. A. and Ljubimowa, M. N. *Ibid.*, **144**, 669, 1939.
[13] Szent-Györgyi, A. *Stud. Inst. med. Chem. Univ. Szeged*, **1**, 17, 1942.
[14] Weber, A. and Weber, H. H. *Z. Naturforsch.*, **5b**, 124, 1950.
[15] Weber, H. H. *Proc. roy. Soc., B*, **137**, 50, 1950.
[16] Laki, K. and Carroll, W. R. *Nature, Lond.*, **175**, 389, 1955.
[17] Mommaerts, W. F. H. M. *J. biol. Chem.*, **188**, 553, 1951.
[18] Tsao, T.-C. *Biochim. Biophys. Acta*, **11**, 227, 1953.
[19] Straub, F. B. and Feuer, G. *Ibid.*, **4**, 455, 1950.
[20] Weber, A. *Ibid.*, **19**, 345, 1956.
[21] Tsao, T.-C. *Ibid.*, **11**, 236, 1953.
[22] Szent-Györgyi, A. 'Chemistry of Muscular Contraction'. 2nd edition. Academic Press. New York, 1951.
[23] Marsh, B. B. *Biochim. Biophys. Acta*, **9**, 247, 1952.
[24] Weber, H. H. and Portzehl, H. *Progr. Biophys.*, **4**, 60, 1954.
[25] Hasselbach, W. and Schneider, G. *Biochem. Z.*, **321**, 461, 1951.
[26] Hanson, J. and Huxley, H. E. *Nature, Lond.*, **172**, 530, 1953.
[27] Hasselbach, W. *Z. Naturforsch.*, **8b**, 449, 1953.
[28] Huxley, H. E. and Hanson, J. (In preparation.)
[29] Hanson, J. and Huxley, H. E. *Symp. Soc. exp. Biol.*, **9**, 228, 1955.
[30] Huxley, A. F. *Progr. Biophys.* (In press.)

Edmond Halley (1656–1741)

SIR EDWARD BULLARD

To his contemporaries, and for a long time after his death, Halley was the 'second most illustrious of Anglo-Saxon philosophers'. Today most people know that he predicted the return of the comet of 1682 and that he persuaded Newton to write the *Principia*, but his own most original work has gradually been forgotten. The three hundredth anniversary of his birth on 29th October 1656 provides an appropriate occasion to look again at the life and work of a truly great man of prodigious versatility and most attractive personality.

Halley was the son of a prosperous London soapboiler.[1] When nearly seventeen years of age he went to The Queen's College, Oxford. While there he conceived a plan for making a catalogue and map of the southern stars. With characteristic impetuosity he left Oxford without taking a degree, and with the help of Sir Jonas Moore, the Master of the Ordnance, obtained a letter from the King recommending the East India Company to transport him and a friend to St Helena. On arrival Halley found the island to be almost continually covered by cloud, and consequently had great difficulty in obtaining the necessary observations during the year he was there. The results were published in 1679 in a catalogue giving the positions of 341 stars; the map shown in figure 2 was also published at about the same time. In addition he observed a transit of Mercury across the disc of the sun. He realized that this constituted a powerful method of determining the solar parallax and it is noticeable that throughout his life returned again and again to the subject, particularly recommending the observation of the transit of Venus which would occur in 1761. At St Helena he noticed that he had to shorten the pendulum of his clock to make it keep time; this had previously been observed by Richer at Cayenne, but these experiments were not known to Halley.

When Halley returned to Oxford he found himself in a difficulty which is not uncommon today. He had done an excellent piece of original work, but had not done it in Oxford and had not fulfilled the University's requirements for a degree. The Provost of his college was anxious to help him, but expected 'to find opposition among the Masters, who are difficult both to remit exercises and to give time'. Fortunately Halley had powerful friends who procured a letter from the King recommending to the Vice-Chancellor that he be given the degree of M.A. 'without performing any previous or subsequent exercises'.

The journey to St Helena was of critical importance in his career. On it he made his first substantial contributions to knowledge, and in connection with it he became known to the King and to several others who were eminent in science and politics. In 1678, soon after his return, he was elected a Fellow of the Royal Society. It was probably also this voyage that awakened his interest in the sea and started the stream of ideas on hydrography, diving, the winds, terrestrial magnetism, and the saltness of sea water, which occupied his most fruitful years.

After his catalogue of the southern stars was published he spent two years travelling on the continent. First, in 1679, he visited the aged Hevelius at Danzig and attempted to resolve the acrimonious dispute with Hooke about the relative merits of open and telescopic sights on astronomical instruments. Though Halley remained convinced of the superiority of the latter he failed to convince Hevelius, and was surprised to find that observations with open sights were often reproducible to 10 seconds of arc. He succeeded in staying on good terms with both disputants.

When he got home from his travels Halley was 25 years of age. A few months later he married Miss Mary Tooke, of whom almost nothing is known except that she was 'a young lady equally amiable for the gracefulness of her person and the beauties of her mind, in whose society he lived happily for fifty-five years' [3]. He seems then to have had no need to earn his living and decided to devote his time to astronomy. During the next three years he started a series of observations designed to last for 18 years, to correct the tables of the moon. Such a lengthy project was ill suited to his temperament, and he was soon diverted to other things.

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[1] E. F. MacPike [1, 2] has collected and published most of the available information about Halley; in view of this, references are not given here for statements whose origin can be traced in MacPike's books. The most detailed life of Halley is that in the 'Biographia Britannica' [3].

In 1684, when he was 27, he visited Cambridge to see Newton, then aged 43, and asked him whether he could prove that a planet would move in an ellipse if the sun attracted it with a force proportional to the inverse square of the distance. Newton said that he had proved this some time before, but could not lay his hand on the paper and would send it later. A few days later he sent two proofs. Halley fully realized the importance of what Newton had done, and with great skill and tact drew him on to develop his ideas, to communicate them to the Royal Society, and to publish them in 1687 in the *Principia*. The story is well known and is told by all biographers of Newton; here it is sufficient to say with De Morgan that 'but for him, in all human probability, that work would not have been thought of, nor when thought of written, nor when written printed.' Halley saw the book through the press, paid for the printing, and wrote the prefatory Latin verses.

It is clear from many expressions in his letters that Halley had a profound respect and devotion for Newton, and on many occasions went to considerable pains to help him. For example, in 1695 he offers to reduce Flamsteed's observations of the comet of 1680 'being desirous as far as you will permitt it, to ease you of as much of the drudging part of your work as I can, that you may be better at leisure to prosecute your noble endevours'. On first seeing the manuscript of the first book of the *Principia* he calls it 'your incomperable treatise', the third book is 'your divine treatise' [5], and nearly forty years later he calls Newton 'the person in the Universe I most esteem'.

In 1686 Halley had become Clerk, or what would now be called Assistant Secretary, to the Royal Society. The portrait of him that hangs in the room of the present Assistant Secretary was painted at about this time; it is reproduced in figure 1. He held this position for thirteen years. During this time he carried on a large part of the correspondence of the Society and attended almost all meetings both of the Society and of the council. He edited the Transactions and undertook to write five sheets in every twenty. He took part in discussions on the most diverse subjects and is recorded in the journal book as having spoken at twenty-six meetings during 1691. In 1692 he is known to have written or spoken on the measurement of the speed of ships, terrestrial magnetism, the origin of springs and rivers, diving bells, the methods of making diving suits watertight, the grinding of telescope mirrors, the flow of water from a hole in a vessel, the invention of an instrument which is a forerunner of the modern marine sextant, the size of objects seen under water, a support for a compass needle, the accuracy of his observations at St Helena, a possible slowing of the moon in its orbit revealed by ancient eclipses, a method of moving excavated earth, the prediction of eclipses, the design of a coelostat, lunar theory and methods of observation, a method of securing a ship's guns in bad weather, and 'the figure of the Caepia'. This flow of ideas, inventions, and experiments continued for years. Some of the subjects are a little trivial, but many are of the highest originality, ingenuity, and interest. Perhaps the most striking of his investigations at this period are two papers in the Transactions for 1683 and 1692 respectively [6] on the variation, or, as it is now called, the declination, of the magnetic compass.

In the first paper Halley collects 55 observations taken between 1580 and 1682 at 47 different places. He uses these to refute Gilbert's suggestion that the variation is due to the attraction of the north pole of the needle by the magnetized masses of the continents and Bond's suggestion that it can be accounted for by the attraction of a dipole inclined to the earth's axis of rotation. Another suggestion, due to Descartes, ascribed the variation to masses of iron and lodestone. Halley points out that, although there undoubtedly are local attractions, the main features of the variation are of continental extent '*ex. gr.* in the whole Indian Sea, the Needle declines the same way, and that regularly, 'twill follow that the attracting Substance that occasions it, must be very far distant.' In his first paper Halley suggests that four poles in the Arctic regions are sufficient to account for the observed variation all over the world. The arguments are qualitative, since 'to calculate exactly what it is, in any Place assign'd, is what I dare not yet pretend to', since observations are few and many of them of doubtful accuracy, 'and besides, it remains undetermin'd in what proportion the attractive Power decreases, as you remove from the *Pole* of a Magnet, without which it were a vain Attempt to go about to calculate'. A few years later Halley made some experiments in the courtyard of Gresham College with 'the Society's great magnet'. These experiments give a good indication of an inverse cube law, but Halley seems never to have referred to them again, perhaps because they gave the variation of force with distance outside the magnet and not the variation over the surface, which was what he needed.

In the second paper Halley considers the secular change of the declination. By many examples he shows that the phenomena 'do sufficiently evince, that the whole Magnetical System is by one, or perhaps more motions translated . . . that this moving thing is very great, as extending its Effects from Pole to Pole, and that the Motion thereof is not *per saltum*, but a gradual and regular Motion' westward. He points out the great difficulty that this raises for all theories of terrestrial magnetism; for 'considering the Structure of our Terraqueous Globe, it cannot be well suppos'd that a very great part thereof can move within it without notably changing its Center of Gravity and the Equilibre of its Parts, which could produce very wonderful Effects in changing the Axis of diurnal Rotation, and occasion strange alteration in the Sea's Surface, by Inundation and Recesses thereof, such as History never yet mention'd'. The whole phenomenon is on too large a scale 'and the Places are too far asunder to be influenc'd by the removal of any Magnetical Matter, which may by accident be transplaced within the Bowels, or on the Surface of the Earth'.

This difficulty Halley meets by the bold hypothesis that the earth possesses a core that rotates slightly less rapidly than the outer shell. The shell carries two poles (the fixed magnetic poles of Gilbert) and the core two more. The poles carried by the core move gradually westward relative to the earth's surface owing to the lagging of the rotation of the core behind that of the shell. The elastic and gravitational stability of the system is then briefly discussed and various possible objections mentioned.

It is clear that Halley intended this theory only as a first approximation; he suggests that more than four poles and more than two concentric spheres may be necessary. In a portrait painted when he was 80 years old he holds a diagram taken from his 1692 paper showing three separate concentric spheres within the earth. He estimated the rate of rotation of the core relative to the shell as 0·5° per year, but says 'the nice Determination of this, and of several other Particulars in the Magnetic System is reserv'd for remote Posterity; all that we can hope to do, is to leave behind us Observations that may be confided in, and to propose an Hypothesis which after-Ages may examine, amend or refute.' Modern determinations lie in the range 0·2–0·3° per year.

It is not too much to say that by reading these two papers of Halley's one can learn more about the origin of the earth's magnetic field and its secular variation than will be found in all that was written during the succeeding 250 years. Halley saw the essential points that the widespread anomalies are inconsistent with a local origin and that the time scale of the secular change requires a cause independent of geology, and points to a mobile core. The argument has been carried further in recent years. We now know that the earth has a fluid core and can imagine processes that might maintain electric currents in it, and thus a magnetic field. This gives a greater freedom than Halley's permanently magnetized solid core and allows the foci of the non-dipole field (Halley's extra poles) to wax and wane, as well as moving westward. Halley got as far as he could without electromagnetism, but it is surprising that no one went further for so long.

It is impossible here to discuss every subject that Halley pursued at this period, and the mention of a few must suffice. In 1693 he published a paper entitled 'An Estimate of the Degrees of the Mortality of Mankind, drawn from Curious Tables of Births and Funerals at the City of Breslaw; with an Attempt to ascertain the Price of Annuities of Lives' which gives one of the first attempts to found tables of annuities on a basis of fact. Among his mathematical papers in the Transactions, is one that discusses very clearly some iterative methods for finding the roots of numbers. Such processes have become of importance recently, as they are commonly used in extracting roots by electronic computors; it is surprising to find that Halley was aware of the practical importance of rapid convergence; he knew for instance that if a is an approximate cube root of $(a^3 + b)$ then $a + ab/(3a^3 + b)$ is an approximation in which 'the Figures already found in the Root, would be at least Trebled, which all other ways, are encreased but in an equal number with the given ones'. In another paper he demonstrates that more heat is received from the sun during a summer's day in England than in India. 'A Discourse tending to prove at what time and place, Julius Caesar made his first descent upon Britain' and 'Some Observations and Conjectures concerning the Chinese Characters' are unexpected, but illustrate the width of his interests.

In addition to these investigations he obtained a patent [7, 8] on his improved diving bell in 1691 and promoted a company for using it, the values of whose shares were quoted in the newspapers during the next few years [7]. From numerous references in the journal book of the Royal Society and elsewhere it is probable that this work took up much of his time.

In 1696 Newton was made Warden of the Mint just as the recoinage of all the old silver coin was starting. This was a large undertaking, and, to maintain a sufficient supply of coin, five mints were opened in provincial towns. Halley was appointed deputy controller of that at Chester, where he remained till 1698 [9].

In 1698 Halley returned to London. His return coincided with the visit of Peter the Great to England. The Czar was aged 26 and had recently obtained control of the Russian government; the main object of his visit was to learn about the building and management of ships. Through this interest he came to know Halley, 'admitted him familiarly to his table, and ranked him among the number of his friends' [3]. The story that he pushed the Czar through Evelyn's holly hedge in a wheelbarrow has, so far as I know, no contemporary authority, though the cost of three lost wheelbarrows and of damage to some holly trees is included among £350 paid by the Office of Works for damage done by the Czar to Evelyn's house and garden [8, 10].

Soon after the Czar left, Halley embarked on the great adventure of his life. He was made captain of the *Paramour*, a naval pink (a small merchant ship), and instructed by the Admiralty to sail to the east coast of South America and the west coast of Africa calling at as many islands as possible, and then 'to stand soe farr into the South, till you discover the Coast of the Terra Incognita, supposed to lye between Magelan's Streights and the Cape of Good Hope'. At all these places he was to determine the magnetic declination and the longitude.

He sailed from Deptford in October 1698, but encountered delays due to leaks and unsuitable ballast in his ship. By February 1699 he got as far as Brazil, but by then it was too late in the season to go far to the southward. On this account, and because of trouble with his officers, he turned homeward, arriving in June 1699. After having his first lieutenant court-martialled and reprimanded for insolence, he set out again in the same ship; this time, after calling at the Cape Verde Islands and at Rio de Janeiro, he reached 52½° S latitude, where, on 1st February, he 'fell in with great Islands of Ice, of Soe Incredible a hight and Magnitude, that I scarce dare write my thoughts of it'. He soon found himself 'in Imminent Danger to looss our ship and lives, being Invironed with Ice on all Sides in a fogg soe thick, that we could not see it till [the ship] was ready to strike against it' [17]. He extricated himself from these dangers and returned home by way of Tristan da Cunha, St Helena, Brazil, the West Indies, and Bermuda, arriving at the end of August 1700.

He brought back 115 observations of the magnetic declination; these and other observations were used to prepare a chart of the Atlantic Ocean showing lines of equal declination. This chart is reproduced in figure 4, being the first map to show the declination (or any other quantity) in this way. For a hundred years such lines were known as Hallean lines. In 1702 Halley produced a similar chart, shown in figure 3, covering the whole world. This chart went through many revisions during the next fifty years and was of great value to navigation. Professor Chapman has given a more detailed account of these charts than is possible here [11].

On these voyages Halley made lunar observations to determine the longitude. He also took with him an ingenious barometer designed by Hooke; in this the air pressure was measured by the difference in the readings of a spirit thermometer and of an unsealed air thermometer [12]. Halley says that the instrument gave reliable warning of storms and was the first barometer successfully used at sea.

The next year Halley was again captain of the *Paramour*. He persuaded the Admiralty to let him spend the whole summer 'Observing the course of the Tides in the Channell of England as well in the mid sea as on both shores' and in taking 'the true barings of the principall head lands on the English Coast one from another, and to continue the Meridian as often as conveniently may be from side to side of the Channell, in order to lay down both coasts truly against one another'. He had a most strenuous summer, anchoring all over the Channel; in a letter to the Secretary of the Admiralty he says 'The frequent weighing my ankers in so deep water has been very hard service to my small company, but the greatest difficulty I find, is from the frequent gales of Wind, which, (especially without the Start) raise the sea to that degree that there is no riding', sentiments which will be shared by anyone who has had occasion to anchor a small sailing ship in deep water in this area. At the conclusion of the work Halley produced a new chart of the Channel.

He spent a large part of 1702 and 1703 visiting Vienna and Istria as a representative of the

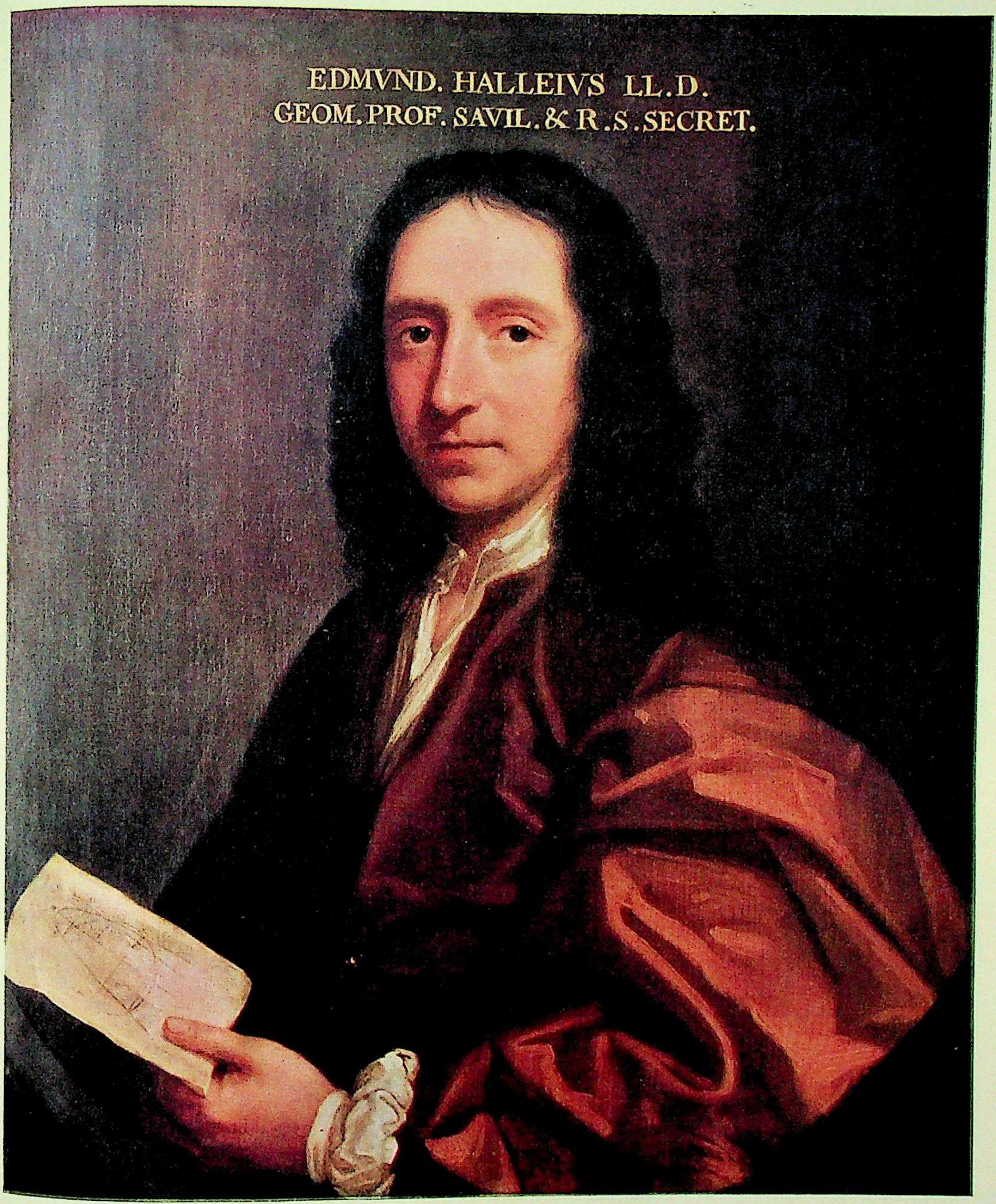

EDMVND. HALLEIVS LL.D.
GEOM. PROF. SAVIL. & R.S. SECRET.

FIGURE 1 – *Halley at the age of about 30. This picture is supposed to have been painted by Thomas Murray. Halley holds a diagram representing a geometrical method of determining the roots of a cubic or biquadratic equation by the intersection of a circle and a parabola. The diagram occurs in two papers published in the* Philosophical Transactions *in 1687. The picture was probably painted at about that time, that is soon after Halley became Clerk to the Royal Society. (Reproduced by permission of the Royal Society.)*

British government, to advise on the fortification of ports on the Adriatic. Halley was now 47 years of age and was one of the best known of the Fellows of the Royal Society, a mathematician, astronomer, and physicist of great distinction, and at the same time a man of the world who 'now talks, swears, and drinks brandy like a sea-captain' [14]. He was not a rich man and had managed to pursue his scientific work only by taking temporary employment first at the Chester mint and then with the Admiralty. Towards the end of 1703 Wallis, the Savilian professor of Geometry at Oxford, died, and Halley was appointed in his place. This was his third attempt to obtain a Savilian professorship. In 1678 Edward Bernard was thinking of resigning his astronomical professorship, and Halley, then a young man of 21 who had not yet taken a degree, was proposed as his successor [15]. In fact Bernard stayed in his professorship till 1691; Halley was then again a candidate, but David Gregory was appointed. It appears that this was due to doubts about Halley's religious views, and in particular to an accusation that he was 'guilty of asserting the eternity of the world'. It is difficult now to judge what Halley's religious views were. They were certainly not strictly orthodox, but I doubt if he was an atheist; he certainly did not believe in the 'eternity of the world', since he saw that this was inconsistent with any friction, however small, opposing the planetary motions. Later he wrote a paper suggesting that the age of the earth might be estimated from the accumulation of salt in the sea, and must, therefore, be finite.

His first undertaking at Oxford was to prepare an edition of the *Sectione Rationis* and the *Conicorum* of Apollonius (he had previously published part of the *Conicorum* in 1700). The greater part of these works was translated from Greek into Latin, but two books of the *Sectione Rationis* and three of the *Conicorum* were known only in Arabic; after a few hints from an Arabic scholar Halley produced a satisfactory translation, including a restitution of some passages in which the Arabic text was corrupt. One book was lost altogether; Halley restored this from a summary given by Pappus and from references to it elsewhere in Apollonius.

In 1705 Halley completed and published his 'Synopsis of the Astronomy of Comets', which he had started about 1695. He collected all the observations of comets that he could find, going back to that of 1337, and deduced the elements of parabolic orbits for 24 of them. The similarity of the elements of the orbit of the comet of 1682 to those found for the comets of 1607 and 1531 suggested to him that these comets were successive returns of a single body whose orbit was not a parabola but a very elongated ellipse, described in about 75 years. Halley predicted the return of this comet in 1758 and suggested that many other comets would prove to move in elliptical orbits. The discovery had been made in 1695, but was not published till 1705. The earlier empirical attempts by Kepler, Hevelius, and the Cassinis to describe the orbits of comets had had very poor success, and the demonstration that they did move in orbits very close to parabolas was a striking verification of Newton's mechanics. The demonstration that 'their Orbits are dispos'd in no manner of Order; nor can they, as the Planets are, be comprehended within a *Zodiak*, but move indifferently every Way, as well retrograde as direct' shows a striking difference from the planets. Halley also pointed out the possibility of a collision between the earth and a comet.

In 1712 Halley published Flamsteed's astronomical observations. This publication was the culmination of a long-drawn-out dispute in which Halley and Newton endeavoured first to persuade and then to coerce Flamsteed into publishing his catalogue of the fixed stars and the places of the moon and planets derived from his observations. The Royal Observatory at Greenwich had been built and Flamsteed appointed 'astronomical observator' by Charles II in 1675. He had a salary of a hundred pounds a year, but was provided with no instruments and no assistant except a 'silly labourer'. His expenses much exceeded his salary, and he not unnaturally regarded his observations as his own property, as did Halley and Bradley after him. He wished to publish his observations as a complete whole in what he regarded as the logical order, first the observations, then star charts, then the catalogue, and finally the positions of the sun, moon, and planets. This plan of observation and computation he pursued with undeviating rigidity for 45 years. The observations were incomparably better than those in the existing catalogues of Tycho Brahe and Hevelius, which were made with plain sights. The results were urgently needed for the practical purposes of navigation and by Newton and Halley for the development of dynamical astronomy.

The clash that ensued was probably unavoidable. It is easy to understand the mounting impatience of Halley and Newton as they saw Flamsteed hoarding a mass of important data while he argued about the proper form of the charts of the

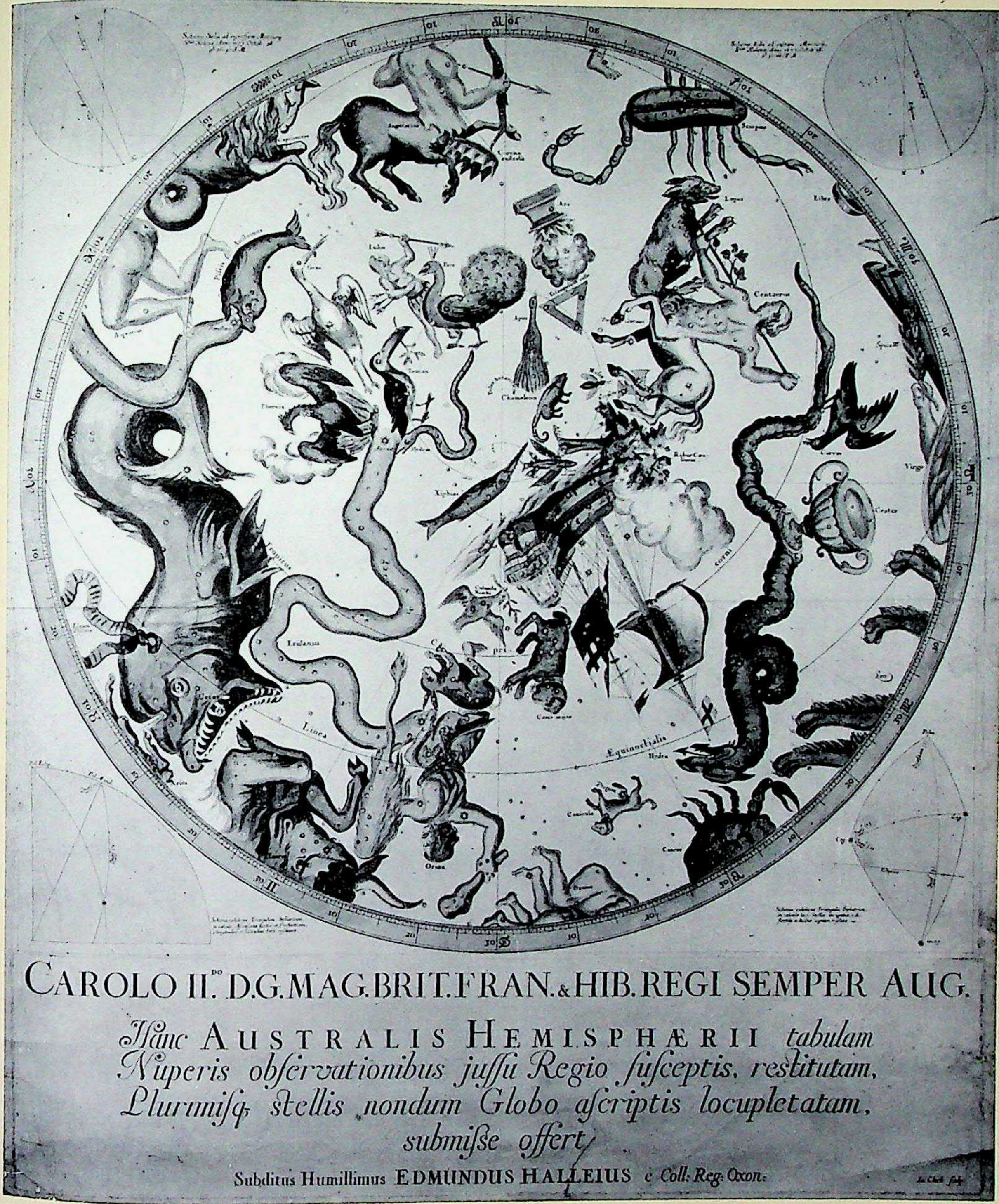

CAROLO II.DO D.G. MAG. BRIT. FRAN. & HIB. REGI SEMPER AUG.
Hanc AUSTRALIS HEMISPHÆRII tabulam
Nuperis obſervationibus juſſu Regio ſuſceptis, reſtitutam,
Plurimiſq; ſtellis nondum Globo aſcriptis locupletatam,
ſubmiſſe offert
Subditus Humillimus EDMUNDUS HALLEIUS e Coll: Reg: Oxon:

FIGURE 2 – *Halley's map of the southern stars based on his observations at St Helena. The map includes a new constellation* Robur Carolinum, *named in honour of Charles II. The small diagrams at the top corners show the transit of Mercury observed at St Helena. This is presumably the map Halley gave to Hooke on* 31st October 1678 [4] *and which Hooke showed to the Royal Society on 7th November. There is a copy in the British Museum bound with Halley's catalogue, but other copies of the catalogue do not contain the map. The author's copy, reproduced here, has never been folded to go in the catalogue; it is therefore probable that it was issued separately.*

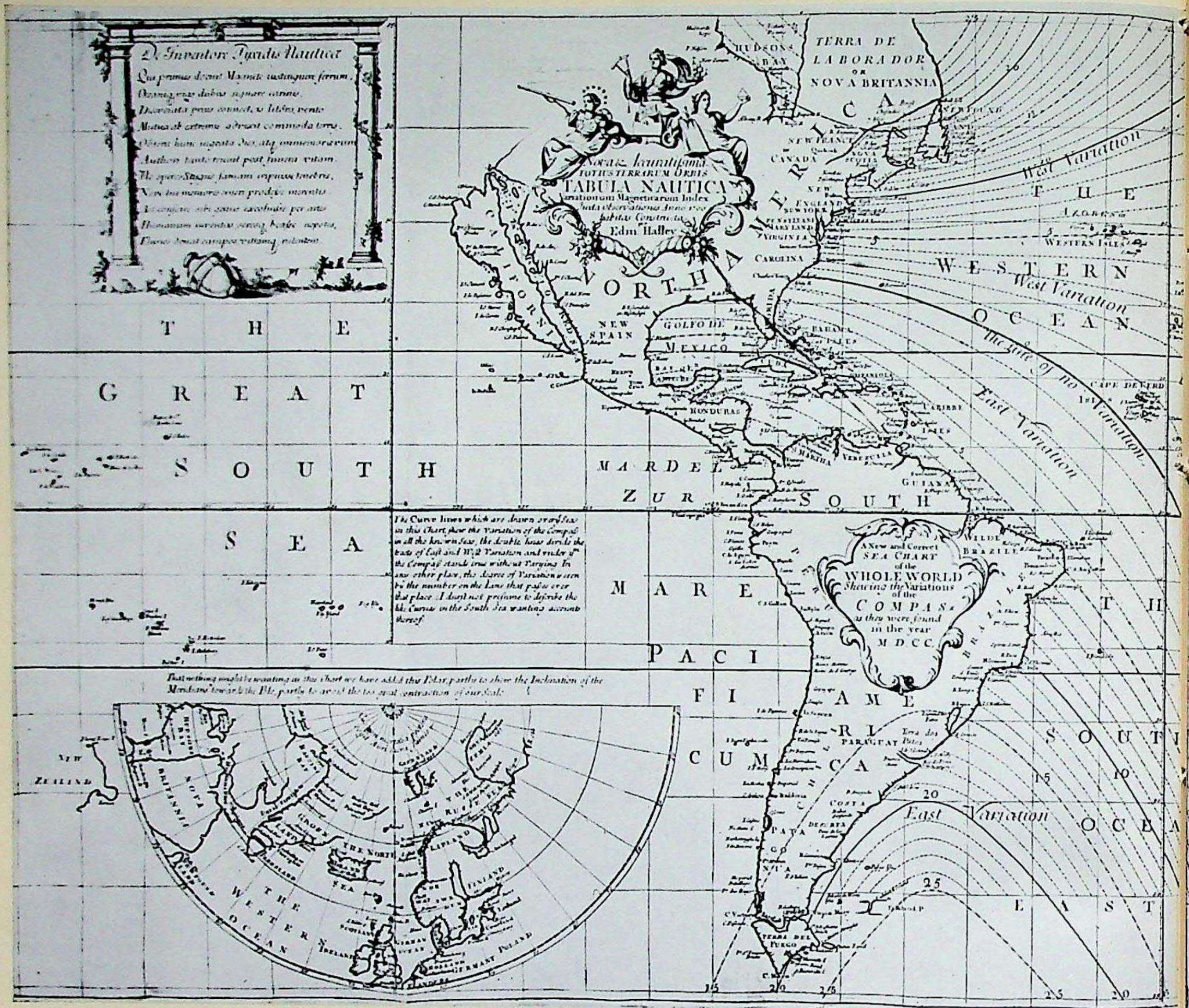
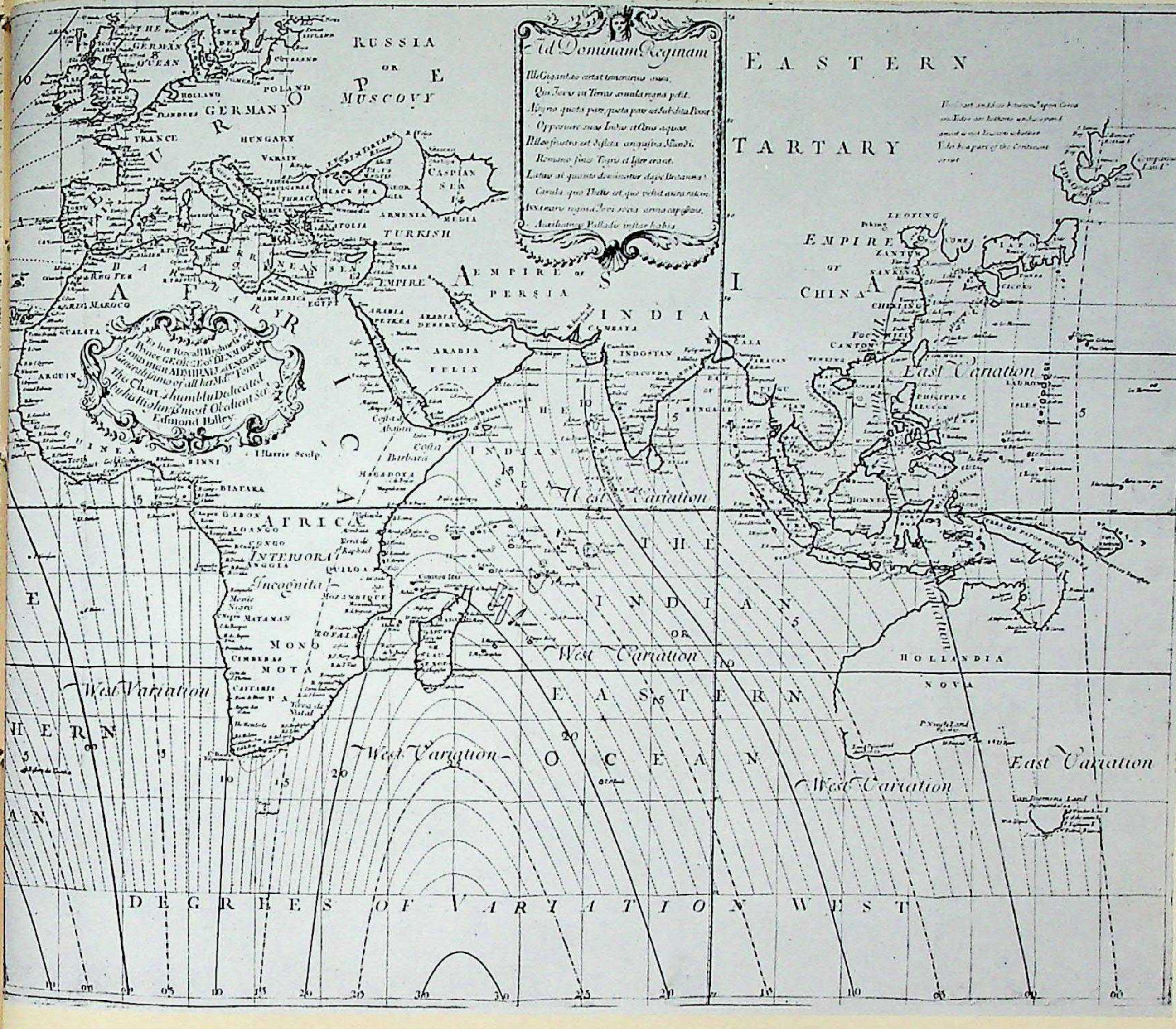

De Inventore Pyxidis Nauticae
Nova & Accuratissima TOTIUS TERRARUM ORBIS TABULA NAUTICA
Edm. Halley
TERRA DE LABORADOR OR NOVA BRITANNIA
HUDSONS BAY
CANADA
NEW FRANCE
NEW ENGLAND
NEW YORK
PENSYLVANIA
MARYLAND
VIRGINIA
CAROLINA
CALIFORNIA
NORTH AMERICA
NEW SPAIN
GOLFO DE MEXICO
HONDURAS
West Variation
THE WESTERN OCEAN
AZORES
WESTERN ISLES
The Line of no Variation
East Variation
CAPE DE VERD
THE GREAT SOUTH SEA
MAR DEL ZUR
MARE PACIFICUM
SOUTH AMERICA
GUIANA
BRAZILE
PARAGUAY
PATAGONIA
TERRA DEL FUEGO
A New and Correct SEA CHART of the WHOLE WORLD Shewing the Variations of the COMPASS as they were found in the year MDCC.
The Curve lines which are drawn over the Seas in this Chart, shew the Variation of the Compass in all the known Seas, the double lines divide the tracts of East and West Variation and under the Compass stands true without Varying. In any other place, the degree of Variation is seen by the number on the Line that passes over that place. I durst not presume to describe the like Curves in the South Sea wanting accounts thereof.
That nothing might be wanting in this chart we have added the Polar parts to shew the Inclination of the Meridians towards the Pole partly to avoid the too great contraction of our Scale
NEW ZELAND
THE NORTH SEA
THE WESTERN OCEAN
IRELAND
SOUTH OCEAN
EAST
15
20
25

FIGURE 3 – *Map of both hemispheres prepared by Halley showing the lines of magnetic declination. Note there*

constellations and the proper Latin names for the joints in the limbs of the mythological figures they were to contain. Flamsteed had come to dislike Halley many years earlier and had been involved in a dispute with him over the tides at Dublin; as the years passed, irritation over the constant pressure to publish his results changed to persecution mania, and in the end no charge was too wild for him to make. Of the Royal Society, with Newton as president and Sloan as secretary, he said ' 'tis governed by persons that either value nothing but their own interests, or understand little but vegetables, and how, by making a bouncing noise, to cover their own ignorance.' He accused Newton of deliberately encouraging the printer to make errors in his catalogue and said that Halley, when helping him 30 years before, had, 'to spoil the Observation, . . . caused me to write *rem*: for *prox*:'. In 1692, in a letter to Newton, he says of Halley 'I have no esteem of a man who has lost his reputation both for skill candor and Ingenuity by silly tricks ingratitude and foolish prate and yet I value not all or any of the shame of him and his Infidel companions being very well satisfied that if χ^t and his Appostles were to walk againe upon earth they should not scape free from ye calumnies


RUSSIA OR MUSCOVY
GERMANY
FRANCE
HUNGARY
EUROPE
Ad Dominam Reginam
EASTERN TARTARY
CASPIAN SEA
BLACK SEA
ARMENIA
TURKISH EMPIRE
EMPIRE OF PERSIA
ASIA
EMPIRE OF CHINA
CANTON
INDIA
INDOSTAN
ARABIA FELIX
AFRICA
BIAFARA
GUINEA
CONGO
Interiora Incognita
MONOMOTAPA
Edmond Halley
East Variation
West Variation
THE INDIAN OCEAN
EASTERN OCEAN
HOLLANDIA NOVA
DEGREES OF VARIATION WEST
5
10
15
20
25
30

re no magnetic lines over the Pacific. This map, subsequently revised many times, was first published in 1702.*

of their venemous tongues, but I hate his ill manners not the man, were he ether honest or but civil there is none in whose company I could rather desire to be' [13, p. 133]. Finally, it became clear that it was impossible to deal with Flamsteed, and Halley published the star catalogue and some other parts of the material in which he and Newton were particularly interested, in the face of Flamsteed's bitter objections.

The detailed history of the affair is a fascinating illustration of the characters of the three main participants: Flamsteed meticulous, always offended, suspicious, and a prig, but also the leading observational astronomer of his age; Newton touchy, often rude, a little inhuman, but really trying to carry out what seemed to him a public duty; Halley, the believer in getting something done, confident that he can reduce Flamsteed's observations better and more quickly than Flamsteed, trying to be tactful and keep on good terms with everyone, but finally exceeding the bounds of prudence and publishing another man's work in the face of his violent opposition. In 1715 Newton's influence with the government was reduced by the death of Halifax, and Flamsteed obtained 300 of the 400 copies of the book printed by Halley.

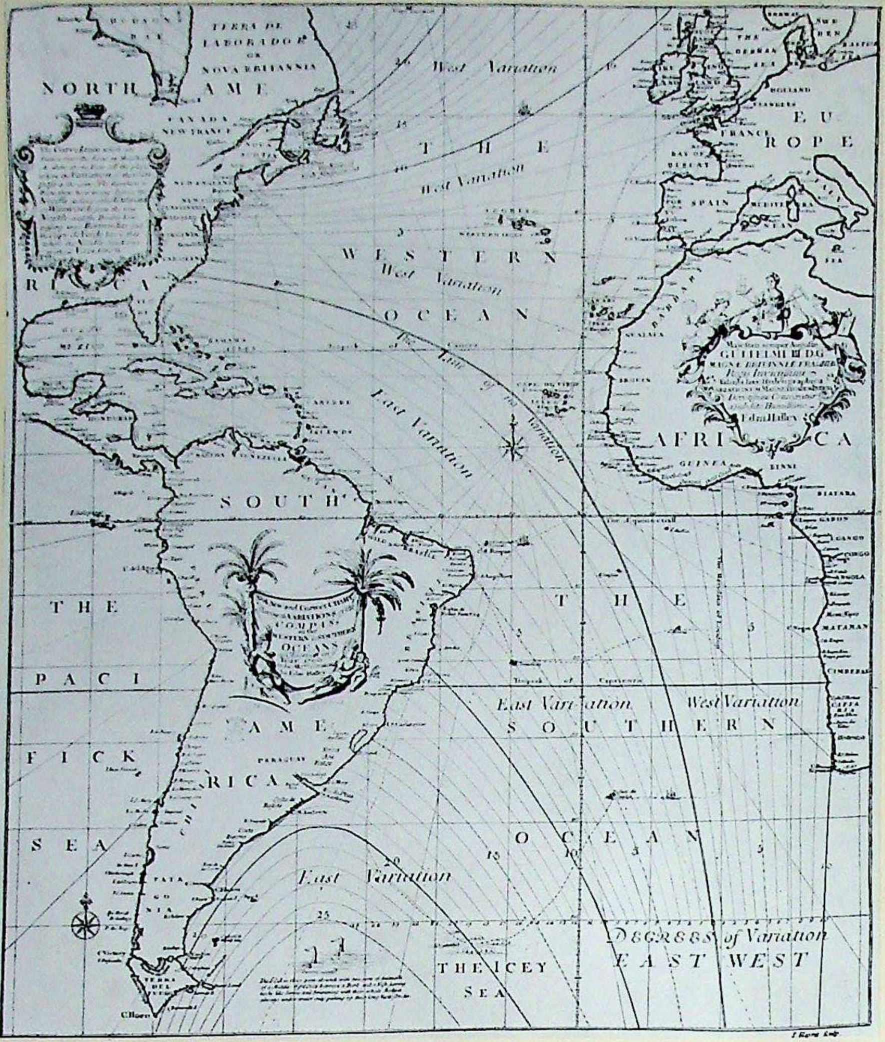

TERRA DE LABORADOR OR NOVA BRITANNIA
NORTH AMERICA
CANADA NEW FRANCE
West Variation
THE WESTERN OCEAN
EUROPE
FRANCE
SPAIN
AFRICA
GUINEA
The Line of no Variation
East Variation
SOUTH AMERICA
THE PACIFICK SEA
THE SOUTHERN OCEAN
East Variation
West Variation
DEGREES of Variation
EAST WEST
THE ICEY SEA

FIGURE 4 – *Halley's map showing the magnetic declination in the Atlantic Ocean. Published 1701.*

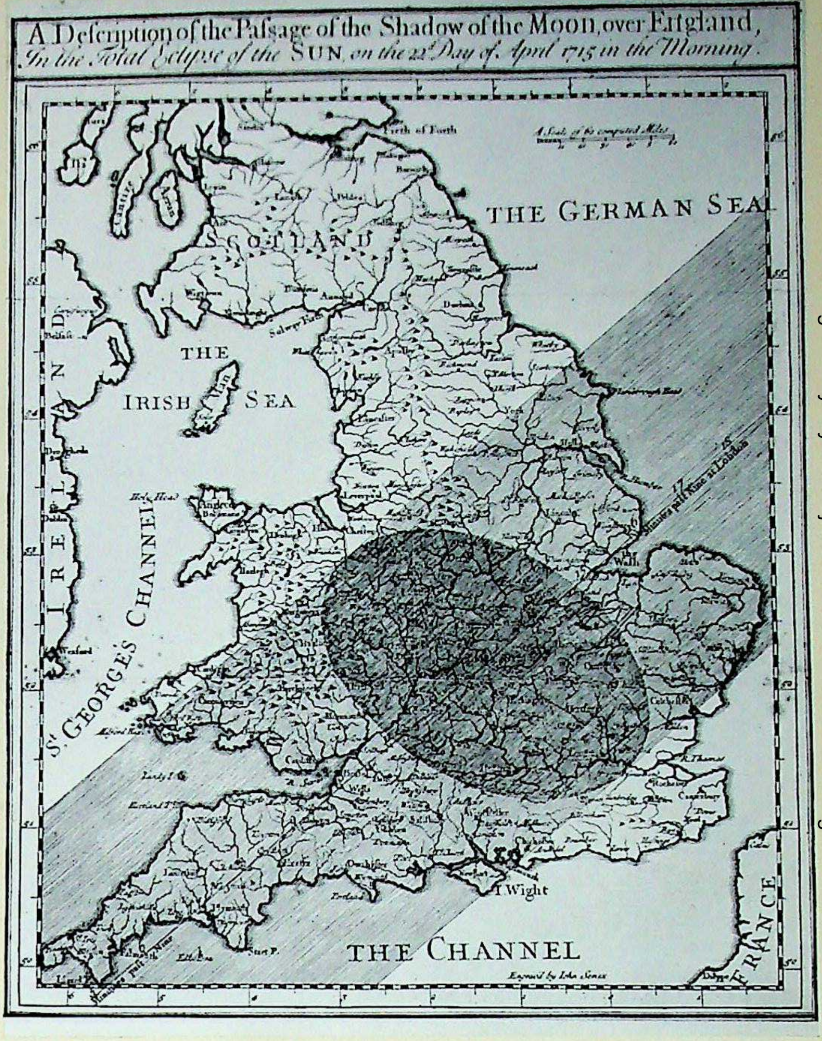

A Deſcription of the Paſsage of the Shadow of the Moon, over England,
In the Total Eclipse of the SUN, on the 22d Day of April 1715 in the Morning.
A Scale of the computed Miles
THE GERMAN SEA
SCOTLAND
THE IRISH SEA
Man
IRELAND
St. GEORGE'S CHANNEL
I Wight
THE CHANNEL
FRANCE
Engrav'd by Iohn Senex

FIGURE 5 – *Halley's map based on observations of the total eclipse of 1715.*

From each copy he extracted 97 sheets containing his observations and burned the rest. These 97 sheets were afterwards used as part of the *Historia Coelestis* published after Flamsteed's death by his widow.

During the next few years Halley published a number of papers, mostly on astronomical topics. The most interesting concerns his collection of observations of the total eclipse of the sun visible at London in 1715. He viewed the eclipse himself from the roof of the rooms of the Royal Society and describes the corona and prominences. His map based on the observations is reproduced in figure 5.

In 1720 Flamsteed died, and Halley succeeded him as Astronomer Royal. He found the observatory stripped of all instruments by Flamsteed's executors, and it was some time before he could start effective observation. He then, at the age of 65, embarked on the project he had formed 40 years before, to observe the moon through the 18-year period of the Saros. In this he succeeded, though the work was not in all respects satisfactory [16], and he has the dubious distinction of being the only Astronomer Royal whose observations it has not been thought necessary to publish. His astronomical tables were published posthumously in Latin in 1749 and were reprinted several times in English and French.

Towards the end of his long life Halley became a little infirm, probably as the result of a stroke. He also lost all his teeth and lived largely on fish. He had, however, 'a vein of good humour, which neither his abstracted speculations, the infirmities of old age, nor the palsey itself, which seized him some years before his death, could impair: and this happy disposition, the gift of nature, was the more perfect, as it was still attendant upon that peace of mind, which is the nobler endowment of virtue' [3]. He died, still Savilian Professor of Geometry, Astronomer Royal, and a Naval Captain on half pay, at the age of 85 in 1742.

Looking back at Halley's multifarious activities and achievements, it is perhaps as a collector and organizer of data that his genius is most apparent. Again and again he collects a mass of information of varying reliability, containing many errors and contradictions, and reduces it to order. He did this with the magnetic observations, with the tides in the Channel, with the comets, with the eclipse of 1715, and with the moon's orbit. His remarkable work on the path of the great meteor of 1719 is of the same kind, and so is his discussion of the trade winds. He was often a rash speculator and we now know that he was sometimes wrong in his conclusions. He had, however, a very sound instinct for physics; in mathematics, his work was outstanding. Some of the things he was most interested in have again become fashionable subjects of study only in our own day; Halley therefore appears to us not as a mere follower of Newton, but as the fountain head of many of our own interests. That he was also the first man who borrowed a ship from the Admiralty for an expedition with a scientific purpose, and the man who persuaded the government to pay for the instruments at Greenwich Observatory, increases our gratitude to him and our respect for his powers.

REFERENCES

[1] MACPIKE, E. F. 'Correspondence and papers of Edmond Halley'. Oxford University Press, London. 1932.

[2] *Idem.* 'Hevelius, Flamsteed and Halley'. Taylor and Francis Limited, London. 1937.

[3] 'Biographia Britannica', 2494–2520. 1757.

[4] 'The diary of Robert Hooke', edited by H. W. ROBINSON and W. ADAMS. Taylor and Francis Limited, London. 1935.

[5] BREWSTER, D. 'Memoirs of the life, writings and discoveries of Sir Isaac Newton'. Constable and Company Limited, London. 1855.

[6] HALLEY, E. *Phil. Trans.*, 13, 208, 1683; 17, 468, 1692.

Both these papers are reprinted in 'Miscellanea Curiosa'; the quotations in the text are taken from the second edition of this book.

[7] HOUGHTON, J. 'A collection for the improvement of husbandry and trade'. London. 1692–1700.

[8] Calendar of State Papers, Domestic.

[9] CRAIG, J. 'Newton at the mint'. Cambridge University Press, London. 1946.

[10] *Notes and Queries.* (2), 1, 365, 1856.

[11] CHAPMAN, S. *Occas. Notes R. astr. Soc.*, No. 9, 117, 1941.

[12] HALLEY, E. *Phil. Trans.*, 22, 791, 1701.

[13] BAILEY, F. 'An account of the Revd. John Flamsteed'. Admiralty, London. 1835.

[14] Letter from Flamsteed to his former assistant A. Sharp dated 8th December 1703, reproduced in [13].

[15] Letters from Flamsteed to Bernard dated 22nd January and 8th February 1677–8, reproduced on p. 667 of the supplement to [13].

[16] BAILEY, F. *Mem. R. astr. Soc.*, 8, 169, 1835.

[17] DALRYMPLE, A. 'A collection of voyages chiefly in the southern Atlantick Ocean'. London. 1775.

The dynamics of the pneumatic tyre

G. TEMPLE

While there is abundant literature on the technological and engineering aspects of the pneumatic tyre, there appears to have been relatively little treatment by the physicist and applied mathematician. The mechanical behaviour of the tyre is here examined in terms of its reaction to the various forces arising during manœuvring of the wheel and the vehicle. Although results of much interest have been obtained, the complex structure and behaviour of the tyre have so far precluded the establishment of a complete and satisfactory theory.

The dictionary describes the pneumatic tyre as an endless air-cushion fitted to the rim of a wheel in order to improve its riding qualities. This description does scant justice, however, to a major invention in transport, worthy to take its place with the ice-skate and snowshoe and almost as great a triumph of engineering as that pre-eminent discovery—the wheel. This article will focus attention on the essential properties of the pneumatic tyre as a medium for the transmission or suppression of forces between the wheel and the ground. The pneumatic tyre will be called here simply the tyre, the other species of this genus being distinguished as solid tyres.

The behaviour of the tyre can be most strange, and even the light cast by Newtonian dynamics is scarcely adequate to elucidate all its mysteries. Even today the tyre is full of surprises and still provides a rich field for research. Just as all the problems of structural engineering are found in their most acute and intractable form in aeroplane construction, so all the problems of tyres are accentuated to the utmost when they are fitted to the wheels of aircraft. Considerable impetus has been given to tyre research by problems posed by the landing-run, taxying, steering, and braking of aircraft wheels, and the most valuable available compendium of information on the mechanical characteristics of tyres was issued as an Aeronautical Research Council Report [1].

CLASSIFICATION OF PROBLEMS

From the point of view of the natural philosopher, if not from that of the engineer, the mechanical behaviour of the tyre is conveniently and systematically studied in terms of its reactions to the various kinds of forces which are elicited during different manœuvres of the wheel and of the vehicle to which it is fitted.

First, the tyre is called upon to support the vertical axle load, either as a steady load, while the vehicle is at rest or running over the ground, or as a variable load, as when an aircraft is landing on a runway.

Secondly, the tyre is the medium for the transmission of the fore and aft horizontal forces which are effective in driving or braking the wheel.

Thirdly, the tyre is invoked to supply the sideways horizontal forces which are required in steering.

The manœuvres just listed may all be described as natural, but there are also certain artificial manœuvres employed in testing tyres which require examination—the types of static deformation used in tests of tyre elasticity, the steady rolling motion in the 'crab walk,' the self-aligning property, and last, but not least important, the oscillatory motion known as shimmy or wobble.

The complexity of the structure and behaviour of the tyre are such that no complete and satisfactory theory has yet been propounded. The characteristics of the tyre still present a challenge to the natural philosopher to devise a theory which shall co-ordinate the vast mass of empirical data and give some guidance to the manufacturer and user. This is an inviting field for the application of that method of idealization which is a standard technique in the application of mathematics to the physical world.

IMPORTANCE OF GROUND REACTIONS

Consider a wheeled vehicle accelerating on a level road. What is the cause of this motion? For the magistrate it is the driver in charge of the vehicle; for the engineer it is the engine which provides the propulsive power; but for the applied mathematician it is the forward thrust exerted by the road on the wheels or tyres. For the layman this is a difficult conception, but it is an inescapable conclusion from Newton's first law of motion. According to this, only external forces are effective in producing acceleration, and (on the level) the only external forces are provided by the road and the resistance of the air. The same conclusion follows if the vehicle is being retarded or steered round a corner. It is the reaction between the tyres and the ground which provides the necessary force. Hence the prime subject of our study must be the reactions between the tyre and the ground.

When we study the wheel and tyre as a closed dynamical system we must also include the forces transmitted to the wheel through the axle, the driving couple, braking force, the steering force applied to the wheel, and the adhesion between the tyre cover and the rim of the wheel. These forces determine the motion of the wheel and tyre, and the ultimate goal of our investigation is to determine the response of the wheel and tyre to these forces in terms of the measurable characteristics of the tyre.

It is a sobering thought that all the forces required to drive, brake, or steer the car are transmitted through the tyre—a channel-shaped envelope of rubber, strengthened with a warp and woof of cord threads and by the bead wires along the edges of the tyre cover, and deriving almost all its rigidity from the air pressure in the inflated inner tube.

VERTICAL LOADS AND FREE ROLLING

The stress system in a free inflated tyre—as observed, for example, when the axle is jacked up until the tyre is clear of the ground—is comparatively simple. The air pressure is resisted by circumferential and transverse (hoop) stresses in the cover, and by a longitudinal tension in the bead (figure 1), which presses uniformly on the rim of the wheel. But when the jack is removed and the load of the vehicle begins to press on the axle the situation is much more complex, even when we neglect the effects of camber and 'toe-in'.

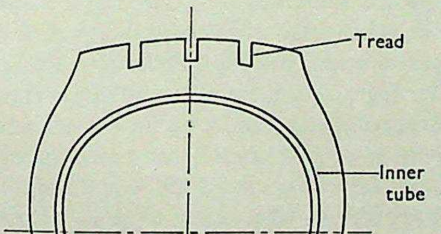


FIGURE 1 – *Cross-section of tyre.*

The tyre becomes squashed by the upward pressure of the ground, and the load carried by the wheel is roughly equal to the product of the inflation pressure—by which is meant the gauge pressure, i.e., the excess over atmospheric pressure as indicated in the standard tyre pressure gauge—and the area of the contact region. But, of course, the load is not transmitted by the air, but by stresses in the tyre cover. In fact the tyre cover functions in the same way as the tensioned spokes of a bicycle wheel, which support the axle by reason of the increased tension in the spokes above the axle, and the reduced tension in the spokes below. Similarly the axle of a car hangs in the tyre (figure 2), being carried by the difference between the increased transverse tensions above and the reduced transverse tensions below.

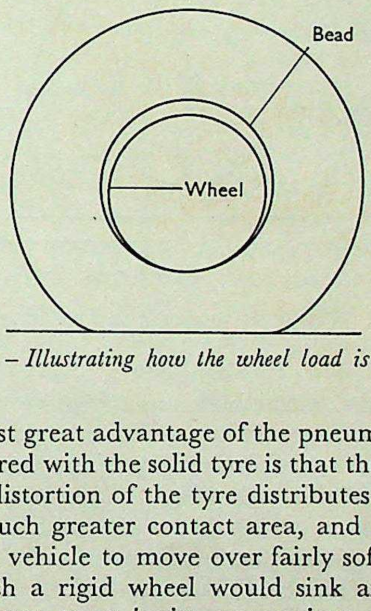


FIGURE 2 – *Illustrating how the wheel load is carried by the tyre.*

The first great advantage of the pneumatic tyre as compared with the solid tyre is that the squashing and distortion of the tyre distributes the load over a much greater contact area, and therefore enables a vehicle to move over fairly soft ground into which a rigid wheel would sink axle-deep. Low-pressure tyres invite comparison with the padded soles on the feet of a camel, which expand when the camel is fully loaded and reduce the contact pressure to about seventeen pounds per square inch. High-pressure tyres, such as are used on many civil aircraft, may have an inflation pressure of 100 pounds per square inch, and of course they can be used only on hard runways with a good thickness of concrete on a stabilized subsoil.

The great advantage of the wheel is the lower resistance which it elicits from the ground when freely rolling, and this advantage is retained when the wheel is fitted with a pneumatic tyre. The rolling resistance, i.e. the ratio of the horizontal drag D to the vertical load W, varies with the forward speed, the softness of the ground, and the type of tyre. At lower speeds on hard roads a representative figure for the rolling resistance is 20 pounds per ton, or 1 per cent.

The horizontal drag has a moment about the axle and therefore tends to give angular acceleration to the wheel. To balance this effect the vertical reaction of the ground must move forward a distance x from the centre of the contact region and produce a decelerating moment about the axle such that $Wx = Dh$, where h is the height of the axle above the ground (figure 3). This movement of the centre of pressure is doubtless associated with the adoption of an unsymmetrical shape by the rolling tyre.

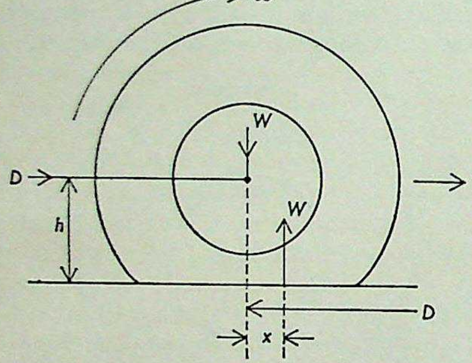


FIGURE 3 – *Forces acting during free rolling with uniform forward velocity* V.

The third attractive characteristic of the tyre is the 'cushioning' effect which it produces when rolling over obstacles and uneven ground. The way in which this effect is produced is that obstacles are, as it were, swallowed by the tyre, which distorts in such a way that the axle continues to move horizontally as the wheel rolls over the obstacle. The extraordinary efficiency of this process can be appreciated by estimating the vertical acceleration produced when a rigid wheel of radius R rolls with speed V over an obstacle of height h (figures 4(a) and 4(b)). The maximum vertical velocity and acceleration are easily proved to have values exceeding hV/d and $2hV^2/d^2$ respectively, where $d = (2Rh - h^2)^{\frac{1}{2}}$ is the distance through which the wheel moves forward as it rises over the obstacle. The maximum vertical acceleration therefore exceeds V^2/R. In a wheel of 3 feet diameter, moving at 30 miles per hour, this gives the fantastic figure of 15 times the acceleration due to gravity.

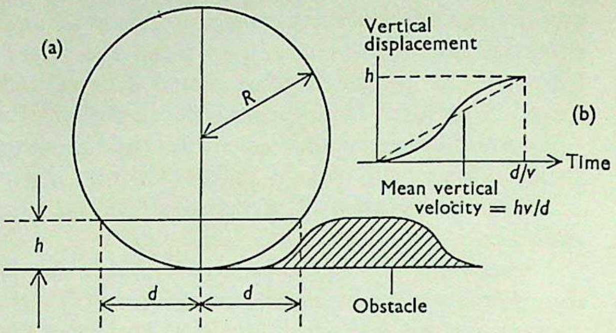


FIGURE 4 – *Rigid wheel riding over an obstacle.*

To complete this rapid summary of the action of the tyre in sustaining vertical loads, reference must also be made to the function of aircraft tyres as shock absorbers in the touchdown. Here the tyres co-operate with the hydraulic shock absorbers in the main undercarriages in absorbing the kinetic energy of the vertical component of the velocity of the aircraft on landing.

A curious and interesting feature of the rolling motion of a tyre is the relation between the effective rolling radius r and the height of the axle above the ground (figure 5). The rolling radius is defined as the ratio of the forward linear speed V of the axle to the angular velocity of the wheel ω. Experiments show that at low speeds the rolling radius is less than the radius R of the free, inflated, and undeflected tyre by about one-third of the tyre deflection δ. This can be deduced theoretically as follows: Let $2l$ = chord $AB = 2R \sin\theta$ in figure 5, and arc $AB = 2R\theta$. Now $2\theta/\omega = 2R\sin\theta/V$, and $\delta = R(1 - \cos\theta) \simeq \frac{1}{2}R\theta^2$. We therefore have for the rolling radius

$$r = V/\omega = R\sin\theta/\theta \simeq R(1 - \tfrac{1}{6}\theta^2) = R - \tfrac{1}{3}\delta.$$

This is probably the explanation of the known fact that the accuracy of speedometer readings is insensitive to variations in tyre pressure and deflection.

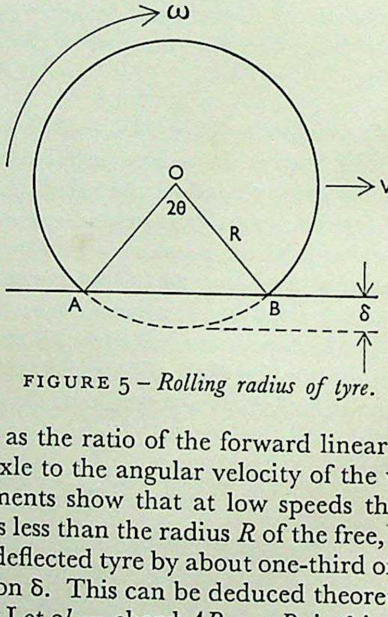


FIGURE 5 – *Rolling radius of tyre.*

The compressive strain on the tyre is given by

$2R(\theta - \sin\theta)/2R\theta \simeq \frac{1}{6}\theta^2 = \frac{1}{3}\delta/R$, that is, one-third of the ratio of the tyre deflection to its undeflected radius. This calculation is confirmed by experiment.

HORIZONTAL FORCES AND BRAKING

The stress system in the tyre cover when a driving torque or a braking torque is applied to the wheel is highly complex, but there are simple approximate expressions for the empirical values of the ground reaction which is elicited. There are few facts available for the driven wheel but abundant information on the effect of braking.

The maximum braking effect is limited by three conditions—the adherence of the tyre to the wheel, where the bead presses against the rim; the maximum shear stress which the cover can carry without tearing; and the adherence of the tyre to the ground. It is the last condition which is most important. Its effect is to limit the retarding force, which acts in the contact region, to the product of the vertical load by the coefficient of ground friction. This coefficient of friction can vary over a wide range, from 1·0 for treaded tyres on dry ribbed concrete to 0·1 or less for smooth tyres on an icy runway.

The maximum ground friction is obtained when there is skidding over the whole of the contact area. This condition always occurs when an aircraft touches down and the wheels, which are initially non-rotating, are spun round by ground friction. During this process, which occupies about a tenth of a second, a thin surface layer of the rubber of the tyre cover is melted by the heat generated, there is a puff of smoke from the burning rubber, a characteristic squeal, and a black mark of melted rubber left on the runway. Surprisingly enough the tyre wear produced is negligible, and pre-rotation of the wheels before landing is as unnecessary as it would be difficult.

It is perhaps even more interesting to study the régime of moderate braking. Its effects are conveniently measured by the wheel slip, i.e. by the percentage reduction in the angular velocity from the value appropriate to pure rolling. The application of the brake imposes a tensile stress on the tyre, with the result that the tyre has an initial tensile strain before it enters the contact area. This increases the effective rolling radius, and the effect persists until the slip is numerically equal to the compressive strain in the contact area of the freely rolling tyre.

Under these conditions limiting friction will first occur at the rear of the contact area and will extend forward as the braking effect is increased. The total frictional drag on the contact area is proportional to the slip until the condition of limiting friction is attained all over the contact area. Thereafter the frictional drag is roughly constant and equal to the maximum value quoted above (figure 6).

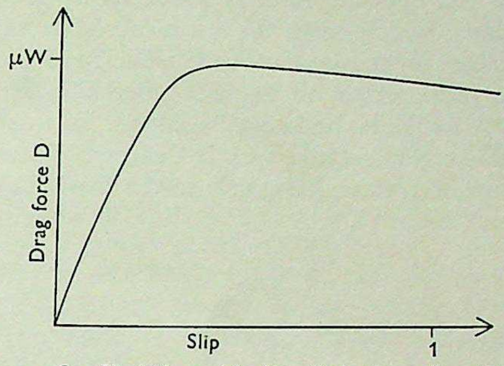


FIGURE 6 – *Variation with slip of the drag force* D *on a braked wheel.* (W = *wheel load,* μ = *coefficient of friction.*)

SIDE FORCES AND CORNERING

The nature of the sideways horizontal forces exerted by the ground on the tyre during cornering and similar manœuvres is best appreciated in the light of a qualitative theory of tyre characteristics. In this theory attention is concentrated on the central line which runs round the periphery of the tyre cover. This equatorial line is sometimes called the tread line. The problem is then restricted to a consideration of small lateral displacements of this line from its normal position in the free and undeflected tyres. In order to obtain a simple representation of the elastic characteristics of the tyre it is assumed that the tread line behaves like a stretched string restrained by a continuously distributed restoring force proportional to its displacement. Its elastic behaviour will then be specified by two parameters—the restoring force per unit length per unit lateral displacement K, and the equivalent tension in the tread line, which is conveniently written as $K\sigma^2$, where σ has the dimensions of a length. The problem is then to express all the lateral elastic properties of the tyre in terms of these two parameters K and σ.

It may very well be that it is necessary to introduce as a third parameter the effective flexural rigidity of the tread line and to think of this line as resisting sideways deformation not only as a spring and as a stretched string, but also as a beam. The consequences of this assumption have not been worked out in any detail.

The two fundamental measurements of tyre characteristics determine the lateral and torsional elasticity of the loaded tyre as it stands or rests on the ground. The wheel and tyre are maintained in a vertical plane by suitable fixing couples. To measure the lateral elasticity, a horizontal side force F is applied at the axle, while an equal and opposite force is provided by ground reactions, which hold the contact region fixed. The sideways movement of the wheel, a, is found to be proportional to the side force F, and the ratio $N = F/a$ is the lateral elasticity. In this test the lower part of the tyre is deflected sideways as the wheel moves relatively to the fixed contact region (figure 7).

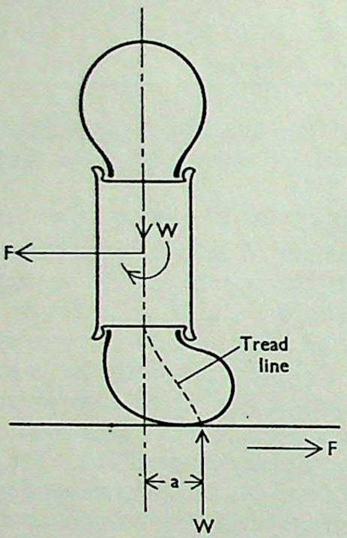


FIGURE 7 – *Illustrates the principle of the measurement of lateral elasticity, the ratio of the side force* F *to the wheel sideways movement* a.

To measure the torsional elasticity, a torque T about a vertical axis is applied to the wheel, an equal and opposite torque being provided by ground reactions. The angular rotation of the wheel, α, about the vertical axis is proportional to the torque T, and the ratio $S = T/\alpha$ is the flexural elasticity.

It is not difficult to carry out these tests for automobile tyres, but it is a major operation to do so for aircraft tyres because of their size and the heavy loads which have to be applied. The numerical values obtained for the lateral and torsional elasticity vary considerably with the different types of tyre [1]. The theoretical values, which depend only on the parameters K and σ and the semi-length l of the contact region, are

$$N = 2K(\sigma + l)$$

and

$$S = 2Kl[\tfrac{1}{3}l^2 + \sigma(\sigma + l)].$$

The automobile engineer is interested not so much in these fundamental elastic constants as in the behaviour of the tyre as the vehicle is steered round a corner. In this manœuvre the tyre executes a kind of 'crab walk', the plane of the wheel being inclined at an angle of yaw θ to the direction of motion of its centre. The elements of the tyre in the contact area adhere to the ground, so that in the contact area the tread line remains parallel to the direction of motion of the centre of the wheel, and the contact area is deflected sideways. As a result a side force F acts on the tyre in the contact region at a distance c behind the vertical through the centre of the wheel (figures 8 and 9).

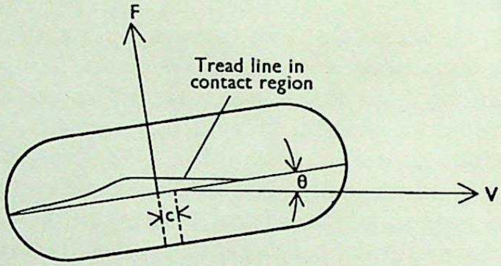


FIGURE 8 – *Side force* F *in 'crab walk' at a cornering angle* θ.

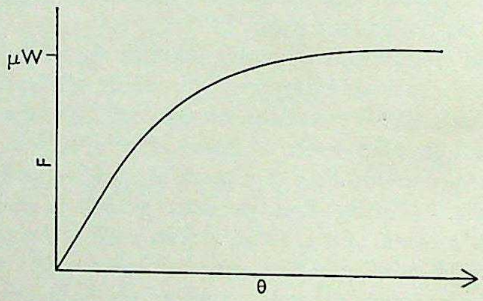


FIGURE 9 – *Variation of side force* F *with the angle of yaw* θ *during cornering.*

The cornering power F/θ is given theoretically (for small values of θ) as

$$F/\theta = 2K(\sigma + l)^2$$

and the pneumatic castor, c, as

$$c = l[\tfrac{1}{3}l^2 + \sigma l + \sigma^2]/(\sigma + l)^2.$$

It is the cornering force F which provides the external force necessary to give the vehicle the sideways acceleration corresponding to a turn with speed V in a turning circle of radius r. In order to study the characteristics of a car during steering it is, of course, necessary to consider the cornering forces on all four wheels, together with the rolling of the chassis on the springs.

There is another type of motion of the wheel and tyre which is extremely curious and interesting for the information which it can give about the tyre parameter σ. In this type of motion the initial configuration is the same as for the measurement of the lateral elasticity, i.e. a suitable side force and couple are applied to the loaded wheel so as to compel it to move sideways while the contact area of the tyre is held fixed by adhesion to the ground. The wheel is then compelled to move forward in its own vertical plane. It is then found that the contact region of the tyre gradually moves sideways (as well as forward) until it is under the centre of the wheel. The track of the tread line on the ground is a die-away exponential curve, with an equation of the form

$$g = g_0 \exp(-x/\sigma),$$

so that its sub-tangent is of constant length, exactly equal to the tyre parameter σ, and is therefore appropriately called the relaxation length. This curious effect, first discovered by Kantrowitz, is easily incorporated into the elementary theory of the tread line described above. The direct measurement of the relaxation length (usually comparable with the tyre radius) is obviously of great value in providing a value of σ, which can be used to check the theoretical values of the lateral and torsional elasticity.

WHEEL WOBBLE OR SHIMMY

The pneumatic tyre also has the power of developing spontaneous oscillations in which the wheel swings to and fro about a vertical diameter. This type of instability usually occurs only at high speeds, and it is well known to racing motor-cyclists and car drivers. The literature of the subject is extensive, and the technical language extremely expressive.

Automobile engineers speak of this type of wheel vibration as wheel wobble or shimmy, and they regard it as one of the many kinds of wheel fight with which the driver has to contend. In the case of cars it is thought to be produced by a coupling between wheel flap and car shake, i.e. between the oscillation of the wheels about the king-pins and a rolling or yawing oscillation of the car body. In the case of aircraft the oscillation of the fuselage seems to be of small importance, and the main factor is the interaction of wheel oscillation with tyre distortion.

The simplest way of regarding shimmy in aircraft wheels is to emphasize the difference between the side forces acting on the tyre under steady conditions, when the wheel makes a fixed angle with its direction of advance, and during oscillation, when the wheel is swinging to and fro. In the second case the side force is no longer in phase with the angular displacement of the wheel, but lags behind. This is largely due to the fact that changes in the position of the contact region are not instantaneous, but are effected by new elements of rubber entering the front of the contact region. These changes are then propagated through the contact region with the same speed as the speed of advance of the wheel.

It is well known that a lag in the restoring force of a spring is roughly equivalent to the addition of negative damping, which naturally produces a divergent oscillation. When the amplitude of the oscillation becomes so large that the tyre skids at the end of each swing, a régime of steady oscillation is produced. The vehicle becomes uncontrollable, and structural damage may be produced by the violence of the vibrations. The simplest cure is to introduce sufficient torsional damping into the wheel suspension or tyre to suppress shimmy, but not too much to make steering and castoring difficult.

Shimmy in pneumatic-tyred wheels can be compared with the more familiar wheel wobble in the solid-tyred wheels of luggage trucks and the domestic tea trolley. In these vehicles shimmy is usually associated with a fair amount of slack in the mounting of the wheels on their axles. This slack allows the wheel to slide sideways on its axle and introduces a certain lag in the development of the side force on the wheel due to ground friction. Small oscillations can therefore grow into persistent oscillations, with an amplitude controlled by the amount of slack on the wheel axle.

A large number of factors control the development of shimmy, and a complete theory is elaborate and complex.

CONCLUSION

This article does little more than summarize the bald facts concerning the dynamics of the pneumatic tyre, but even so it will be apparent that this is a subject not only of immediate practical interest to the car driver and aircraft pilot, but also a topic of considerable intrinsic interest to the applied mathematician.

For further information on the subject the reader is referred to the report by Hadekel [1], to the publications of the Road Research Laboratory of the Department of Scientific and Industrial Research, and of the Society of Automotive Engineers.

REFERENCE

[1] HADEKEL, R. Aeronautical Research Council Report No. 15888, November 1952.

The bubble chamber

C. DODD

Modern machines can provide pulses of high-energy particles at intervals of a few seconds, which is considerably more rapidly than the detecting devices hitherto in use can be operated. An important feature of the newly developed bubble-chamber detectors is that they can keep pace with the new particle accelerators. They possess the further important features that they have no background of irrelevant tracks and that, because of the high density of the medium, there is a relatively high probability of a collision being recorded.

Progress in high-energy nuclear physics depends largely on the availability of suitable particle detectors, in particular of those giving a photographic record of the paths of high-energy particles and of the fragments resulting from their collisions with other nuclei. The Wilson cloud chamber, using a gaseous medium, and the photographic emulsion, using a solid medium, are now well known examples of this kind of detector. It is perhaps not surprising that when changing circumstances emphasized the deficiencies of both these media, physicists should have considered the possibilities of a liquid medium. Circumstances calling for a new type of detector arose from the discovery of two groups of particles, the hyperons and κ-mesons [1] in cosmic ray experiments. The rarity of the natural production of these particles stimulated the design of accelerating machines of much greater energy than before, capable of producing the particles in copious quantities for investigation. It became apparent that, apart from other considerations, neither of the existing types of detector was able to keep pace with the increased output of such machines and that a detector using a liquid medium was more suitable.

The cloud chamber utilizes the fact that condensation of a liquid can occur on ions produced in a gas which has just undergone an adiabatic expansion. The line of liquid drops is photographed as soon as these are large enough, but during the period of growth the original line of drops may be distorted by the swirling produced in the gas by the expansion process: consequently the trace recorded on the photograph is not a faithful representation of the particle track. The density of the gas is low compared with that of a solid or liquid and the probability of an incoming particle making a collision and producing one of these new particles is very small; moreover about ten seconds must elapse before the gas can be re-expanded ready for the next picture. The probability of producing a collision in the chamber can be increased by inserting lead plates in it, but the length of the track then becomes indeterminate and details of the collision are hidden in the plates. A solution to the problem is to increase the density of the gas by raising its pressure to about 100 atmospheres, but this unfortunately increases the cycling time to about 15 minutes. Since modern machines are capable of providing a pulse of particles every few seconds the cloud chamber is unable to take full advantage of their output, which is achieved only with very heavy expenditure. The high-pressure diffusion cloud chamber is continuously sensitive, but the extent of the layer in which tracks can be made visible is too small to reveal all the details of a three-dimensional collision process.

In the photographic emulsion the medium is of sufficient density to ensure a high probability of production of nuclear collisions, but as the plates are sensitive to stray radiation from the time of their manufacture until they are developed, the background of unwanted tracks makes it almost impossible to sort out with certainty events which are associated with each other. Moreover, deflections are imposed on each track as a result of multiple scattering of the particle by the heavy atoms comprising the emulsion: consequently the effect of a magnetic field cannot be used, as it is in the cloud chamber, to determine the momentum of the particle. The tracks formed in emulsions are so short that a microscope must be used to locate and follow them, making the analysis extremely slow.

The bubble chamber depends for its action on the fact that when the external pressure on a liquid is suddenly reduced to a value much less than the saturation vapour pressure of the liquid at the prevailing temperature, boiling does not begin until a finite time has elapsed. During this time the liquid is superheated and in a state of unstable equilibrium which when upset results in the violent formation and growth of bubbles known as 'bumping'. This delay before the onset of boiling is due to the fact that surface tension forces acting on a microscopic bubble in the liquid tend to collapse the bubble, while the internal vapour pressure tends to expand it. The effect of surface tension decreases as the size of the bubble increases: if the bubble exceeds a certain size the net effect is one of expansion, which causes the bubble to grow and reach visible size extremely quickly. The delay thus represents the time required for random thermal fluctuations to produce in the liquid a bubble large enough for such growth to be possible. When the liquid is contained in a smooth vessel this delay can be several seconds [2].

It was discovered by D. A. Glaser [3] in 1952 that an ionizing particle passing through a sufficiently superheated liquid immediately upset the unstable equilibrium and initiated boiling at points in the liquid lying along its path; by high-speed photography he was able to trace the rate of growth of the string of bubbles marking the track of the ionizing particle. The particle produces charged ions in the liquid along its path: presumably this electrical energy reappears as thermal energy which raises the temperature of the liquid in the region of this path. As a result the surface tension tending to collapse any minute bubble in the neighbourhood is decreased and at the same time the internal vapour pressure increases, so that even the most minute bubble formed spontaneously grows in size indefinitely.

If the vessel containing the liquid is made of metal with flat glass observation windows, boiling always begins at the junctions of the metal and glass as soon as the external pressure on the liquid is reduced. If, however, this pressure reduction is carried out very rapidly, the pressure in the liquid away from the walls attains a low value which is maintained for about a hundredth of a second. During this time the liquid is in a superheated state which is immediately upset by the passage of an ionizing particle [4].

Most bubble chambers are now of this type and consist essentially of a thick-walled metal container having two plane glass windows and containing the liquid, which is maintained at a constant temperature considerably above its normal boiling point (figure 2). Pressure sufficient to prevent boiling is applied by compressed air acting on a piston or flexible diaphragm in contact with the liquid. To render the chamber sensitive the compressed air is allowed to escape through a quick-acting valve. The beam of ionizing particles from the accelerator is then pulsed to traverse the chamber, and a few thousandths of a second later, during which time the individual bubbles along the track have grown to a diameter of about 30 μ, an intense flash of short duration is triggered off so that the track can be photographed. The chamber can be recompressed and ready for the next expansion within a few seconds, or even within a fraction of a second: consequently it is possible to use every pulse from the accelerator and to obtain many thousands of pictures in a single day. A substantial fraction of these pictures can be expected to be of use in the study of nuclear collisions and new particle production, for the probability of the incoming particle making a collision is high because of the relatively high density of the liquid medium. Indeed, a bubble chamber only 10 cm long is able to yield as many collision events as a cloud chamber over 40 m long.

Moreover, the tracks formed in a bubble chamber do not suffer from the distortion, due to motion of the medium, which occurs in a cloud chamber, for the photograph is taken only a few milliseconds after the formation of the bubbles and the inertia of the liquid is such that its motion in such a short time is negligible. Another major advantage of the bubble chamber—freedom from a background of unwanted tracks—arises from the fact that the chamber can record tracks only during the brief time, less than a hundredth of a second, that the liquid is in the superheated state. The interpretation of a complicated event on a bubble chamber photograph is thus a much more certain process than it is in a photographic emulsion.

The velocity of a particle can be deduced from the number of bubbles formed per unit length of its track—a procedure similar to droplet counting in cloud chambers and grain counting in emulsions.

Up to the present, every liquid which has been tried has proved to be suitable for use in the bubble chamber, but since the mechanical construction of a chamber strong enough to withstand pressures much in excess of 30 atmospheres is difficult, liquids requiring high operating pressures are to be avoided. Since the operating pressure is roughly two-thirds of the critical pressure, this means that liquids with a high critical pressure, such as water, are unsuitable. Propane, xenon, and hydrogen are the chief liquids in current use. Liquid hydrogen is undoubtedly the ideal medium, since its nuclei are all protons: the collision processes resulting from its bombardment by other

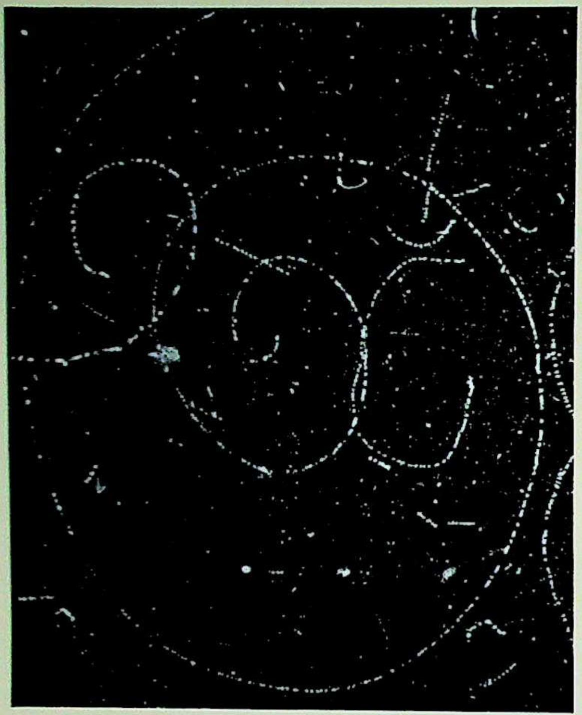


FIGURE 1 – *Photograph of electron tracks taken in a liquid-hydrogen bubble chamber. The electrons are made to follow anti-clockwise spiral paths by a strong applied magnetic field, the imposed curvature increasing as the electron is slowed down by the liquid. (Photograph reproduced by kind permission of Professor Luis Alvarez.)*

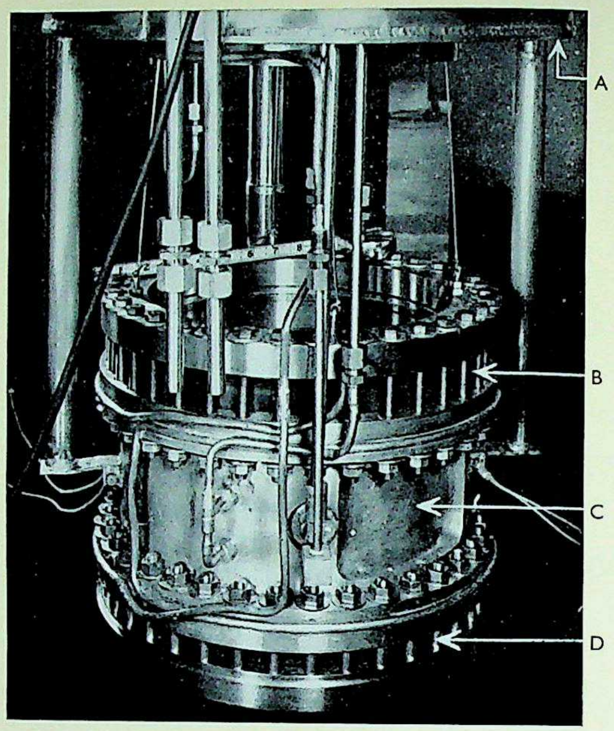


FIGURE 2 – *The liquid-hydrogen bubble chamber of the Radiation Laboratory, California. The sensitive volume is a cylinder of diameter 25 cm and depth 15 cm; the glass windows are 5 cm thick. In operation the chamber must be placed inside an evacuated tank. A, liquid-hydrogen bath; B and D, glass windows; C, stainless steel chamber containing liquid hydrogen. (Photograph reproduced by kind permission of Professor Luis Alvarez.)*

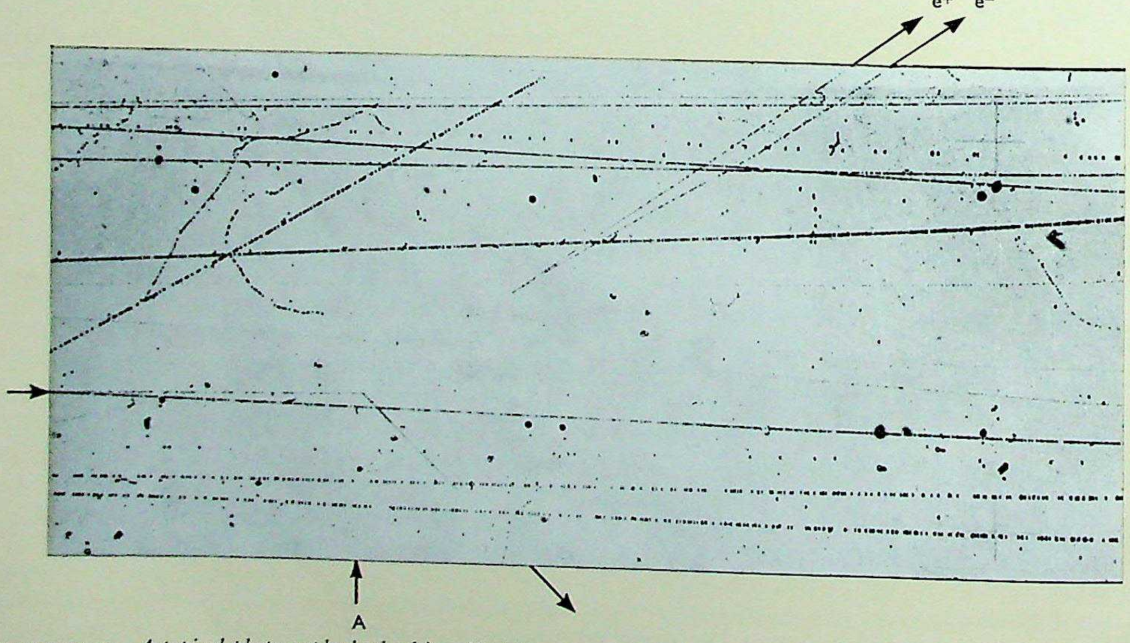


FIGURE 3 – *A typical photograph obtained in a liquid-propane bubble chamber exposed to the 2 GeV beam from the Brookhaven Cosmotron. The beam enters from the left and most particles traverse the chamber, which is 15 cm long, without making a collision. At A an incoming π-meson collides with a proton, producing a γ-ray which leaves no track but whose direction is determined from the tracks of the pair of oppositely charged electrons which it produces. (Photograph reproduced by kind permission of Professor D. A. Glaser.)*

particles produced by machines can thus be more unambiguously interpreted than collisions occurring in any other liquid. The experimental difficulties are, however, very great, since the operating temperature is about 27° A and the pressure about 6 atmospheres. Nevertheless a chamber of diameter 25 cm and depth 15 cm has been operating successfully for some time at the University of California in the 6·3 GeV beam from the Bevatron and in a strong magnetic field which enables particle momenta to be deduced from the curvature which the field imposes on the tracks (figure 1).

In laboratories where a sufficient supply of liquid hydrogen is not available the medium is usually liquid propane, chosen because of its cheapness, its convenient operating temperature (about 60° C), and the fact that it contains only two relatively light atoms, carbon and hydrogen (figure 3). Xenon is attractive as a bubble chamber liquid because its density (about 2·3 g/cm^3) approaches that of a nuclear emulsion, making it possible to have the advantages of the latter technique without its disadvantages. Xenon is extremely expensive, but after the first cost of filling the chamber, it can be used for an indefinite number of exposures without detriment to the liquid. It can thus do the work of thousands of stacks of emulsions, which are expensive to produce and to process after exposure. A xenon-filled chamber is being built at the University of Michigan.

The physical dimensions of a bubble chamber naturally depend on the use for which it is intended. It is hoped in the first instance to learn more about the properties of the newly discovered particles from a detailed study of reactions such as those in which protons bombarded by high-energy π-mesons produce neutral hyperons and κ-mesons, which, being uncharged, do not form tracks in the liquid. Their presence and direction are nevertheless revealed by the tracks of the pairs of charged particles into which they quickly decay. In order that these pairs of tracks shall terminate inside the liquid, the lateral dimensions of the chamber must be about 15 cm if the liquid is propane and about 50 cm if it is hydrogen; the dimension in the beam direction must be at least twice the corresponding lateral dimension. A propane chamber fulfilling these requirements costs very little more than a conventional cloud chamber of similar dimensions, and several are already in operation in the United States, Russia, and England. The development of a liquid hydrogen chamber of the dimensions quoted is far beyond the financial resources of most laboratories, but rapid progress in this direction is being made at the Radiation Laboratory, California, under the direction of Professor Luis Alvarez. A compromise, which is much less expensive, is to use a much smaller hydrogen bubble chamber to produce and identify the event, and to use other neighbouring chambers to stop the long-range products.

The analysis of the data obtained by cloud chambers and emulsions is a slow, laborious process. Much time and skilled effort are required, first to disentangle the really interesting events from the large background of unwanted tracks, and then to perform the various measurements from which velocities, charges, and momenta can be assigned to the various particles participating. Even before the advent of the bubble chamber the unsatisfactory situation had arisen in which data were being accumulated much faster than they could be analysed. With existing techniques the analysis of the photographs produced in a single day by a bubble chamber operating in the beam of a pulsed accelerator would take over a year to complete. A new analysis technique, utilizing existing electronic computers, is therefore essential.

The following technique has been evolved. Instead of re-projecting the two stereo views of the bubble tracks so as to reproduce the actual particle path in space, enlarged images of the two views are projected alongside each other on a screen. A relatively untrained person operates a mechanism controlling a set of cross-hairs so that the centre of the latter follows the direction of each track in turn. The two co-ordinates of individual bubble images on each of the two stereo pictures are punched on to a tape, which is then fed into the electronic computer. The latter gives the three co-ordinates of points along the actual particle path in the chamber, fits a curve to the points, and gives the momentum of the particle which formed the track. In a complicated scattering event it can also give the angles between the directions of the various participating fragments and solve the resulting problems in relativistic mechanics. Using this technique, the time for analysing a track can be reduced to about a minute.

REFERENCES

[1] MASSEY, H. S. W. *Endeavour*, **15**, 117, 1956.
[2] DODD, C. *Proc. phys. Soc. B*, **68**, 686, 1955.
[3] GLASER, D. A. *Phys. Rev.*, **87**, 665, 1952.
[4] GLASER, D. A. and RAHM, D. C. *Ibid.*, **97**, 474, 1955.

The fossil plant cuticle

T. M. HARRIS

The cuticles of fossil plants are of exceptional interest, for they have great chemical stability and in consequence they represent not fossil material in the ordinary sense, but the actual cuticle as it existed on the living plant many millions of years ago. Although this has been known for more than a century, it is only comparatively recently that plant cuticles have been used for practical purposes such as the identification of fossil plant species.

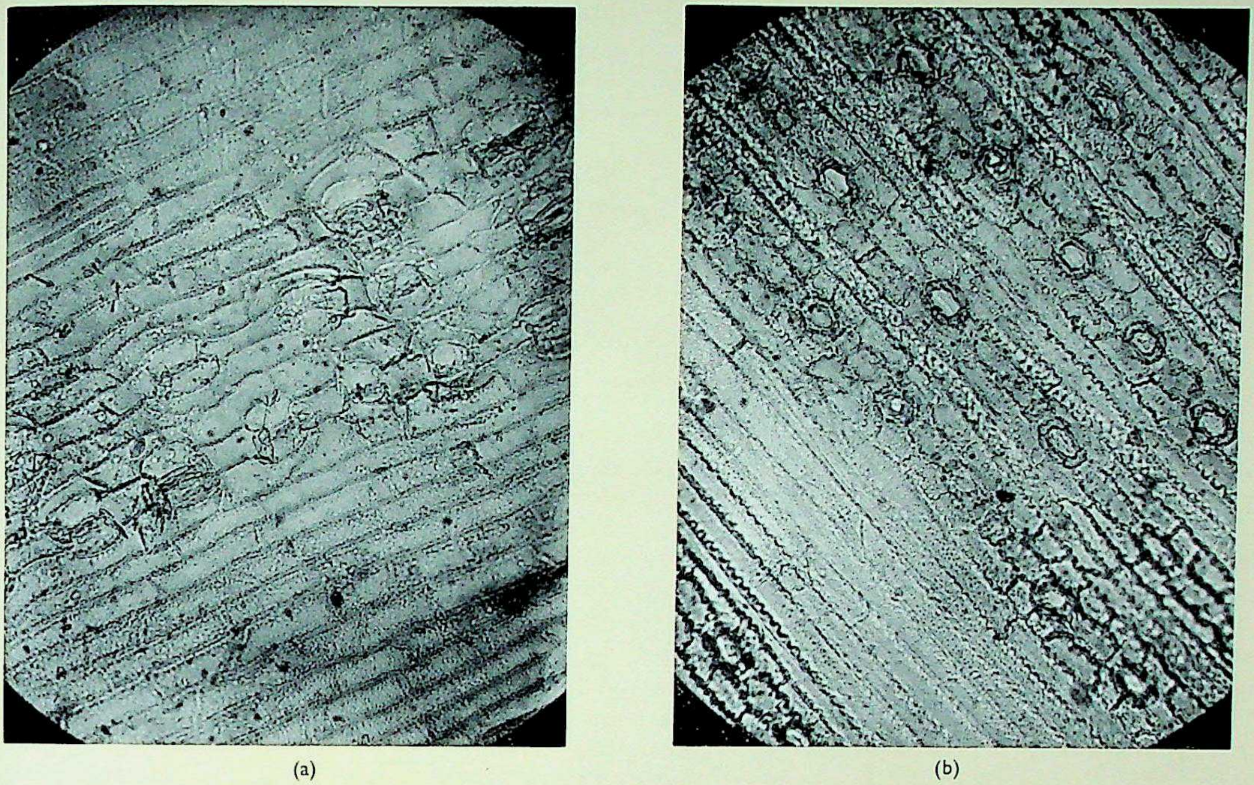
The cell walls of land plants are composed of many materials besides cellulose. Among them is cutin, which forms a tough membrane, the cuticle, outside the epidermis. Cutin is not present in the bud but appears as the leaf expands; it may thicken slowly during the life of the leaf. Cutin is of a wax-like nature and is impervious to water: the cuticle thus helps to conserve water in dry weather. Like a wax, it is readily permeated by dyes such as Sudan III, and it can therefore be readily distinguished in sections by this means. The chemical stability of cutin is remarkable and has important consequences. In the living plant this property is perhaps valuable because it forms a protective film which no organism can at all readily attack; in fossil plants it may allow the cuticle to persist unchanged through millions of years and thus to be available for examination by the fossil botanists of today. Cuticles have been recovered from some of the oldest (Devonian) plants. Finally, the great chemical stability of the cuticle makes its isolation for examination a relatively easy matter, for all that is necessary is to subject the fossil material to a chemical treatment violent enough to dissolve everything else.

Stable though it is, cutin is not entirely resistant to all natural destructive processes, and the cuticles of dead leaves may ultimately be destroyed by bacteria; but the process involved is an aerobic one. However, leaves which become fossils usually do so by falling into rivers and being buried in mud under anaerobic conditions: under such conditions the cuticle will remain intact indefinitely. But like all organic material, cutin may be destroyed by some of the more violent natural forces such as high temperatures and pressures, and thus by no means all plant fossils still possess intact cuticles.

For our present purposes we need not concern ourselves with more than the general nature of the method of isolation now commonly used in the laboratory. The fossil material, such as coal, is put into a mixture of nitric acid and potassium chlorate for a few hours, when its colour gradually changes from black to brown. The material is then rinsed and put into ammonia, when a black solution is formed and the cuticle is left intact as a transparent membrane.

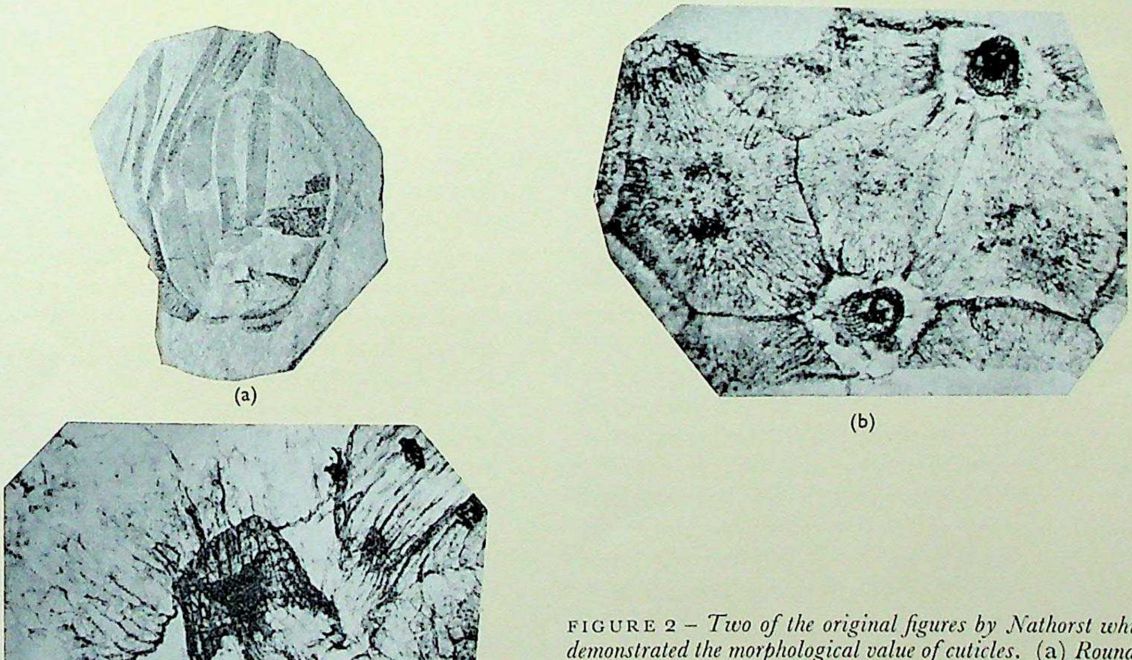
In a leaf such as a pine needle the cuticle forms a thin layer all round the epidermis, and it permeates the cellulose in the deeper layers of the epidermal cell wall. When the cuticle is isolated by a process such as that described above and is spread out on a microscope slide, the outline of every epidermal cell can be seen to be represented by a ridge. The stomata are particularly closely delineated. Thus the cuticle not only has distinguishing characteristics of its own, but to a considerable extent represents the structure of the underlying epidermis: its close study can therefore be most informative. Thus it is often possible to recognize family characters, as in the arrangement of cells round the stomata; generic characters, as in the grouping of the stomata; and specific characters, as in certain details of cell shape. Sometimes, too, the conditions under which the plant has grown can be deduced. Adverse conditions in which the leaf is growing lead to its remaining small: although it has nearly the normal number of cells, each one is comparatively small.

Again, the cuticle can help to solve one of the most vexatious problems in fossil botany—that arising from the fact that a particular fossil often represents only a small fragment of the original plant. Thus, for want of evidence to relate them, fossil remains of different organs of a single species may be assigned to several species. But sometimes the leaf cuticle may provide evidence of relationship, for a characteristic feature shown by it—such as a peculiar kind of hair—may be found on several other organs of the same plant. Again, although leaves are among the commonest of plant



(a) (b)

FIGURE 1 – *Surface views of isolated cuticles and stoma of two conifers.* (a) *Cedar of Lebanon,* C. libani. (b) *Pine,* Pinus palustris. (× 200)



(a) (b) (c)

FIGURE 2 – *Two of the original figures by Nathorst which demonstrated the morphological value of cuticles.* (a) *Rounded fruit (gynaecium) of* Wielandiella; *it is covered by some protective scales.* (*Natural size.*) (b) *Cuticle isolated from the gynaecium, showing polygonal heads of protective scales and two projecting tubes (micropyles) of seeds.* (c) *Details of a micropyle.* (× 90) (*Nathorst* [2].)

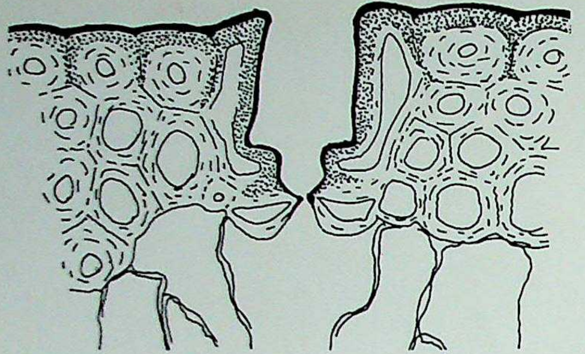


FIGURE 3 – *Section through epidermis of Scots fir,* Pinus sylvestris, *showing a stoma at the bottom of a deep pit. The strongly cutinized layers are solid black, and the weakly cutinized layers stippled.* (× 450)

fossils it is often difficult to assign them to a definite species, for although there may be much variation among the leaves on a single tree there is often no great obvious difference between the leaves of two quite distinct species. The microscopic structure of the leaf cuticle, however, may be quite specific. The precise identification of fossil leaves is important not only to the botanist but to the geologist, for the latter makes much use of them for the identification of rocks.

An interesting example of the importance of the cuticle in the identification of species is provided by certain plant fossils in the Jurassic beds of Yorkshire. Hamshaw Thomas recognized the fruits of two distinct plant species in the Gristhorpe Bed near Scarborough and pointed out that there should be two different kinds of leaf to correspond. But when the leaves, attributed to *Sagenopteris phillipsi*, were examined they seemed to vary continuously in form and thus not to fall into the two groups expected. However, when the cuticles of a large number of specimens were prepared and examined they were at once seen to fall into two well defined groups. One group had straight cell walls, the other sinuous ones. When the leaves themselves were re-examined in the light of this information it was seen that those of one group had, on the average, much broader segments than those of the other. Thus a botanical doubt was unequivocally resolved: the identification of two species of fruit was proved correct by the identification of the two corresponding kinds of leaf.

The converse also happens. A single plant may have leaves of such varied form that individual workers, to each of whom only a few specimens have been available, have attributed them to different species. In consequence the literature becomes burdened with several different names corresponding in fact to only a single species, and this confuses evidence of identification based on less variable organs such as those of reproduction. While the specific identification of fossil leaves such as these must always be to some extent a matter of opinion, the case for including them all within a single species is much strengthened if they have uniform cuticles.

The additional evidence provided by the cuticle is particularly valuable in dealing with small leaves, for their shapes are often of little value in identification. Thus the Conifers have small leaves, and the assignment of their fossil remains to definite groups was until recently in a state of hopeless confusion. Now, however, study of their excellently developed cuticles has completely changed the situation, and the fossil Conifers are, from the point of view of classification, a well defined group, and, in consequence, one very useful for the dating of other remains.

An example of this is provided by certain carboniferous quarries in South Wales, in which there are occasional fissures full of rubbly material

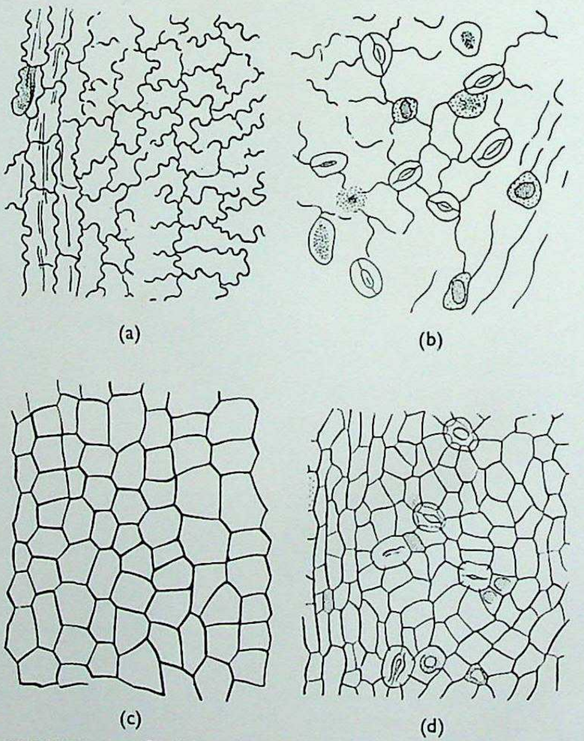


FIGURE 4 – *Cuticles of two Yorkshire species of* Sagenopteris. (a) *and* (b) *Upper and lower cuticles of* Sagenopteris colpodes; (c) *and* (d) *upper and lower cuticles of* Sagenopteris phillipsi. (× 150)

—obviously of later origin—containing bones representing an interesting fauna of small land animals. All that could be said of the age of the animal remains was that they had early Mesozoic affinities and were of an age greater than that corresponding to a stage in the Lower Lias when the sea covered the area and sealed it off. Further evidence was much needed, and a conifer proved valuable. When some of the rubble was dissolved in hydrochloric acid some tiny conifer leaves were obtained; they were only one or two millimetres in diameter and only slightly longer. After suitable preparation, however, their cuticles were found to have a clearly defined structure corresponding precisely to a species, *Cheirolepis muensteri*, which has been found abundantly in the Rhaeto-Liassic rocks of south-west Germany, but not hitherto outside this district or this fairly short geological period. This was therefore a very useful indication of the age of the associated animal remains.

If cautiously interpreted, the cuticles of fossil plants may offer useful information about the climatic conditions obtaining at the time the plant flourished. A good many fossil leaves have thick cuticles and deeply sunken stomata which often have additional protection in the form of pegs, folds of the leaf surface, and hairs. Such organization looks as though it would diminish the loss of water by evaporation, and it is certainly true that in modern plants such 'xeromorphic' features are seen more frequently in plants growing in climates where there are frequent severe droughts than in plants growing in permanently mild climates. There is therefore some evidence of a correlation between xeromorphic form and a dry climate. Notwithstanding his own earlier publications [1], however, the writer believes that although inferences based on this kind of evidence are legitimate they are nevertheless speculative.

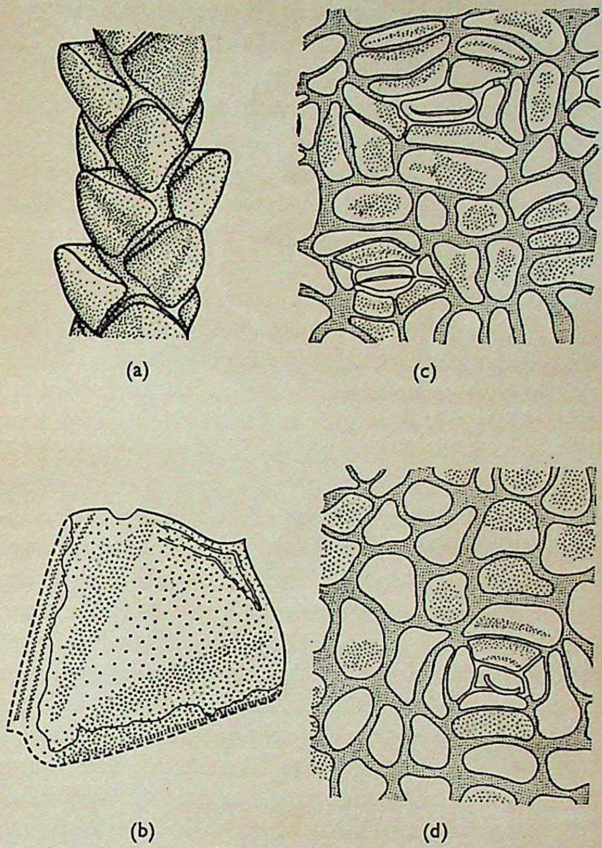


FIGURE 5 – Brachyphyllum mamillare *and* Araucarites phillipsi. (a) *Small piece of twig of* B. mamillare *in restoration* (× 3). (b) *Isolated scale of* A. phillipsi (× 2). (c) *Cuticle from pointed end of* A. phillipsi. (× 400). (d) *Cuticle of leaf of* B. mamillare. (× 300). (*Kendall* [3].)

Plant morphologists can obtain a good deal of useful information from the study of cuticles. Botanists want to understand the organization of every plant organ, and satisfactory methods, taught to students, have been worked out for modern plants. But methods such as microtomy are scarcely applicable to, say, a fossil fruit compressed to a film of coal. Here the cuticle is of extreme value in making the epidermal surfaces available for microscopic examination. The first outstanding success gained in this way was with the gynaecium (seed-producing organ) of the flower of certain Bennettitales. The latter are an extinct group, very different from any now living, and accordingly all our knowledge of them is necessarily derived from fossil remains. A. G. Nathorst [2] recovered some of these compressed gynaecia —discs of coal about 3 cm in diameter and 1 mm in thickness—and noted that their surfaces showed definite fine markings; their nature was, however, obscure. Spectacular results were obtained, however, when fragments of these gynaecia were macerated. It was discovered that the surface was made up of two kinds of units—hexagonal plates, which are now known to be the armoured heads of little scales; and little tubes, which are the micropyles or pollen-receiving parts of seeds. Further work has demonstrated the presence of pollen grains inside the micropyles and various cuticles around and inside the seeds.

The reproductive organs of fossil plants often exist as insignificant little specks of coal, and many of the earlier fossil botanists ignored these as uninformative. Now, however, a tiny fossil seed can be made to yield several cuticles, each with characteristic cells, and possibly also the pollen grains concerned in its pollination.

The problem of fragmentation—the attribution of different organs of the same plant, found in isolation, to different species—has already been referred to. The task of bringing the right ones together is a difficult one, but if we decide to wait until we find a lucky specimen with all its parts joined together we must expect to wait a long time. Often the first suggestion comes from repeated association, but this merely shows that the two organs come from plants of the same kind of vegetation. Many examples could be quoted, but a recent and simple one is provided by the work of Miss M. W. Kendall [3], who has assembled the conifer shoot *Brachphyllum mamillare* with the cone-scale *Araucarites phillipsi*, which have been found together many times. The cone-scale is just like one of the seed-bearing units into which the cone of the Monkey-puzzle (*Araucaria*) falls when ripe; the shoot has tiny scale-leaves like some cypresses and very unlike that of *Araucaria*. Although an *Araucaria* cone-scale is mostly woody, it has a pointed tip which is green like a leaf when young and has an epidermis just like that on the leaf of the same plant. This proved to be so also in the fossils, the cuticle of the tip of *Araucarites phillipsi* being just like that of the leaf of *B. mamillare*, which itself is surprisingly like that of *Araucaria*. Since no other fossils in the flora have a cuticle of this kind, it was concluded that *Araucarites phillipsi* is identical with *Brachyphyllum mamillare*. Subsequently this conclusion was shown to be true by the lucky find of an intact cone on a shoot.

Fossil spores and pollen grains are preserved as cuticles, but they form too big a subject to dismiss in a few words. H. Godwin has previously discussed in this journal [4] the subject of pollen in peat, and all that can be done here is to indicate lines on which work is proceeding.

Geologically speaking, they make excellent zone fossils because they blow about widely and deposit both in marine muds near the coast and in lakes far inland. The oil geologists have found them most useful for correlating such deposits which have no other fossil in common.

On the botanical side, they prove the existence of many plants additional to those which grew beside rivers and formed ordinary fossils. Caution is, however, necessary in the interpretation of results: pollen grains are rather simple things and lose some of their character when flattened, and their identification is often difficult. Thus some workers have reported Dicotyledonous pollen grains from several Jurassic localities, but others dispute the identifications and regard these grains as Gymnosperm pollen or fern spores distorted by compression.

Although the present method of isolating the cuticle from fossil plant material is simple and convenient, it is fundamentally bad in that it completely destroys all other material. We believe that a compressed fossil must include in its coaly substance not only the cuticles but all other tissues that survived bacterial decay, and we feel, too, that we have only to examine it in the right way to be able to display all these tissues clearly.

Already methods exist. The least altered fossil plants can be softened with caustic soda, embedded, and microtomed, but the more compressed ones appear merely as a brown film with only cuticles differentiated. Thomas tried etching such sections (of *Caytonia* seeds) with fluids which would ultimately dissolve the coal. After many failures he succeeded in demonstrating certain thick-walled cells, but the method is laborious and success very rare. More hope lies in the methods of the coal petrologists, who polish and etch an apparently homogeneous piece of coal and can then demonstrate the compressed plant cells. That this has not been seriously tried with compressions is due to there being so few workers and so much work usefully to be done on present lines: there is in consequence little incentive to test new methods. However, when we do learn to display the inner tissues of an ordinary compression, fossil botany will make a further great advance.

REFERENCES

[1] HARRIS, T. M. *Medd. Grønland*, 85, 2, 3, 5, 1931; 112, 1, 2, 1935–37.

[2] NATHORST, A. G. 'Paläobotanische Mitteilungen' 8. *K. Svenska VetenskAkad. Handl.* No. 4. 1909.

[3] KENDALL, M. W. *Ann. Bot., Lond.*, N.S., 13, 151, 1949.

[4] GODWIN, H. *Endeavour*, 10, 5, 1951.

The generation of electricity by fishes

R. D. KEYNES

The ability of certain fishes to generate substantial electric potentials was discovered over two hundred years ago, but it has only comparatively recently become clear how the relatively small voltages produced by the individual cells in the electric organ are added together during the discharge. The discovery that some electric fishes are able to use their discharges as part of a direction-finding system has added fresh interest to the subject.

In September 1751, while travelling in West Africa, Michel Adanson [1] came across the strange fish now known as *Malapterurus electricus*, the electric cat-fish. He wrote: '*Les nègres le nomment ouaniear, et les françois trembleur, à cause de la propriété qu'il a de causer, non un engourdissement comme la torpille, mais un tremblement très-douloureux dans les membres de ceux qui le touchent. Son effet ne m'a pas paru différer sensiblement de la commotion électrique de l'expérience de Leyde, que j'avois déjà éprouvée plusieurs fois. . . .*' This occasion, preceding by some 35 years Galvani's famous observations, seems to have been the first on which the electrical properties of the fish were recognized as such, although the disconcerting consequences of handling it incautiously had long been known. The other fish mentioned by Adanson, *Torpedo*, was familiar to the Romans and Greeks—Scribonius recommended its use to cure chronic headaches and gout—and its discharge was first described as electric by John Walsh [2] in 1773. Two years later, there appeared in the Transactions of the Royal Society a letter to Walsh from an American physician, Hugh Williamson [3], concerning some experiments carried out in Philadelphia on the discharge of the 'electrical' eel, *Electrophorus* (formerly *Gymnotus*) *electricus*. At Walsh's instigation, John Hunter dissected *Torpedo* and *Electrophorus* [4], and his specimens of *Torpedo* are still preserved in the museum of the Royal College of Surgeons. Photographs of two of them are shown in figure 1; they reveal admirably the kidney-shaped electric organs, built up of numerous columns of thin hexagonal 'electroplates', stacked one on another like a pile of pennies, and innervated by four large nerve trunks arising from the electric lobe of the brain.

During the 180 years since Hunter made his dissections, the electric organ has excited the interest of many physicists and physiologists; Franklin, Cavendish, Volta, Davy, du Bois-Reymond, Faraday, and Bernstein are only a few of the eminent scientists who have worked with electric fishes. Most of the early work was concerned in establishing that electricity from 'animate' sources was the same as that from 'inanimate' ones, and in making detailed studies of the anatomy of the electric organ. Several further kinds of electric fish were discovered, including one more with a fairly powerful discharge (*Astroscopus*, the star-gazer of North America, first described by U. Dahlgren in 1906) and, from anatomical evidence, others whose discharge is relatively weak (the rays and skates, a family of African fishes called mormyrids, and the South American gymnotids, closely related to *Electrophorus*). Probably because the discharge of the electric organ was easier to detect, with the relatively insensitive electrical measuring devices available during the nineteenth century, than the smaller voltages produced by muscle and nerve, an almost disproportionate amount of attention was paid to it, judging from the length of the chapters on its properties in the textbooks of about 1900. Yet when it is realized that even with a whole *Malapterurus* at his disposal, du Bois-Reymond [5] had to make his measurements with the device illustrated in figure 4, whose reliability cannot have been of the highest order, it may partly be understood why these same books had little to offer in the way of good explanations of the origin of animal electricity.

In all electric fishes the electric organ consists of large numbers of disk-like cells called electroplaxes or electroplates, each having a nerve connected to one surface but not to the other. The electroplates are arranged in orderly columns, with their innervated sides all facing in the same direction. In *Torpedo* the electroplates lie in the horizontal plane, and are packed very tightly together, forming a wide and thin electric organ whose unit cells discharge in parallel rather than in series, as befits a marine fish living in a medium whose electrical resistance is relatively low. With the exception of *Astroscopus*, the other electric fishes have vertical electroplates, usually separated by quite large spaces and arranged more in series than in parallel. As may be seen from figure 2, the surfaces of the electroplates are often studded with prominent papillae, whose function is presumably to increase the total surface area and hence to lower the effective internal resistance of the organ. The extreme example of specialized development is provided by *Electrophorus*, where the greater part of the lateral four-fifths of the fish is occupied by the electric organ (figure 3). This huge mass of electric tissue is made up of about 70 columns of electroplates, each containing no fewer than 6000 cells in series. On open circuit (i.e. in air) a large electric eel can produce brief (3 msec) pulses of up to 600 volts in potential; short-circuited, the peak current is of the order of 1 amp. The maximum power output is rather more than 100 watts—about half an ampere at 200–300 volts. A large *Torpedo* may generate a current of several amperes at around 50 volts, so that in terms of power output this species is the most potent of the electric fishes. At the other end of the scale, the mormyrids, the gymnotids other than *Electrophorus*, and the rays, have much smaller electric organs, in the form of spindle-shaped structures replacing certain of the caudal muscles, and are capable only of discharges of the order of one or two volts. The discharges of *Astroscopus* and *Malapterurus* are intermediate in size.

The problems which have, perhaps, intrigued physiologists the most, have been to explain how the additive discharge of the electroplates is achieved, and what is the source of the energy dissipated while electric current flows. Until 1900, there was no convincing answer to either question, but at about this time Bernstein [6] made the inspired suggestion that the surface membranes of the electroplates were polarized so that the interior of each cell was negative to the exterior, and that during the discharge the potential across the innervated face collapsed, leaving that across the non-nervous face unaltered. However, although he did some very interesting physical experiments on *Torpedo* [7], which provided strong evidence that the immediate source of energy for the discharge was a pre-existing ionic concentration gradient rather than a chemical reaction, he had no means of testing his main hypothesis. As often happens in physiological research, the problem could not be solved until techniques were available for studying the behaviour of single cells. The appropriate method in this case was the employment of glass micropipettes, 0·5 μ in diameter at the tip, filled with potassium chloride, of the type originally developed by G. Ling and R. W. Gerard [8] in Chicago, which are now being applied extensively for the determination of intracellular potentials. By using pairs of such microelectrodes, connected via a differential direct-coupled amplifier to a cathode-ray oscillograph, and inserting one of them into the individual electroplates in a slice of electric organ, it has recently been shown by H. Martins-Ferreira and the author [9] (working in Professor Chagas's laboratory in Rio de Janeiro), and by H. Grundfest and his colleagues [10] in New York, that, at least for *Electrophorus*, Bernstein was not far from the mark. As may be seen in figure 5, the inside of the resting electroplate is indeed negative to the outside, by some 90 mV, and Bernstein was wrong only in that the potential across the nervous face does not merely collapse during activity, but is actually reversed by about 60 mV. The potential across the non-nervous face barely alters, so that each electroplate contributes 150 mV to the total discharge, in the manner indicated in figure 6.

Investigations on the embryology and comparative anatomy of the electric organ long ago showed that, except in the case of *Malapterurus*, the electroplates are derived from muscle fibres, or perhaps from the special junctional regions called 'motor end-plates', where the motor nerves make contact with the muscles, and where the incoming nerve impulse sets up a corresponding propagated action potential in the membrane of the muscle fibre. It has sometimes been assumed that a study of the electric organ would lead the way to an understanding of the mechanism of neuromuscular transmission, but in fact the reverse has happened, since the elegant work of B. Katz, P. Fatt, J. del Castillo, and others [11] in University College, London, has revealed appreciably more about the properties of the motor end-plate than is known about the electroplate. The main difference between electrical activity at a motor end-plate and that occurring during conduction of an impulse along a nerve or muscle fibre, is that the former depends on the release of a chemical transmitter, acetylcholine, from the neighbouring nerve endings, and cannot be elicited by applied electric currents. On the other hand, nerve and muscle membranes are unaffected by acetylcholine but are electrically excitable. The propagation mechanism depends intrinsically on the spread of electric currents ahead of the advancing impulse. Another difference which is important in the present context is that the depolarization caused by acetylcholine

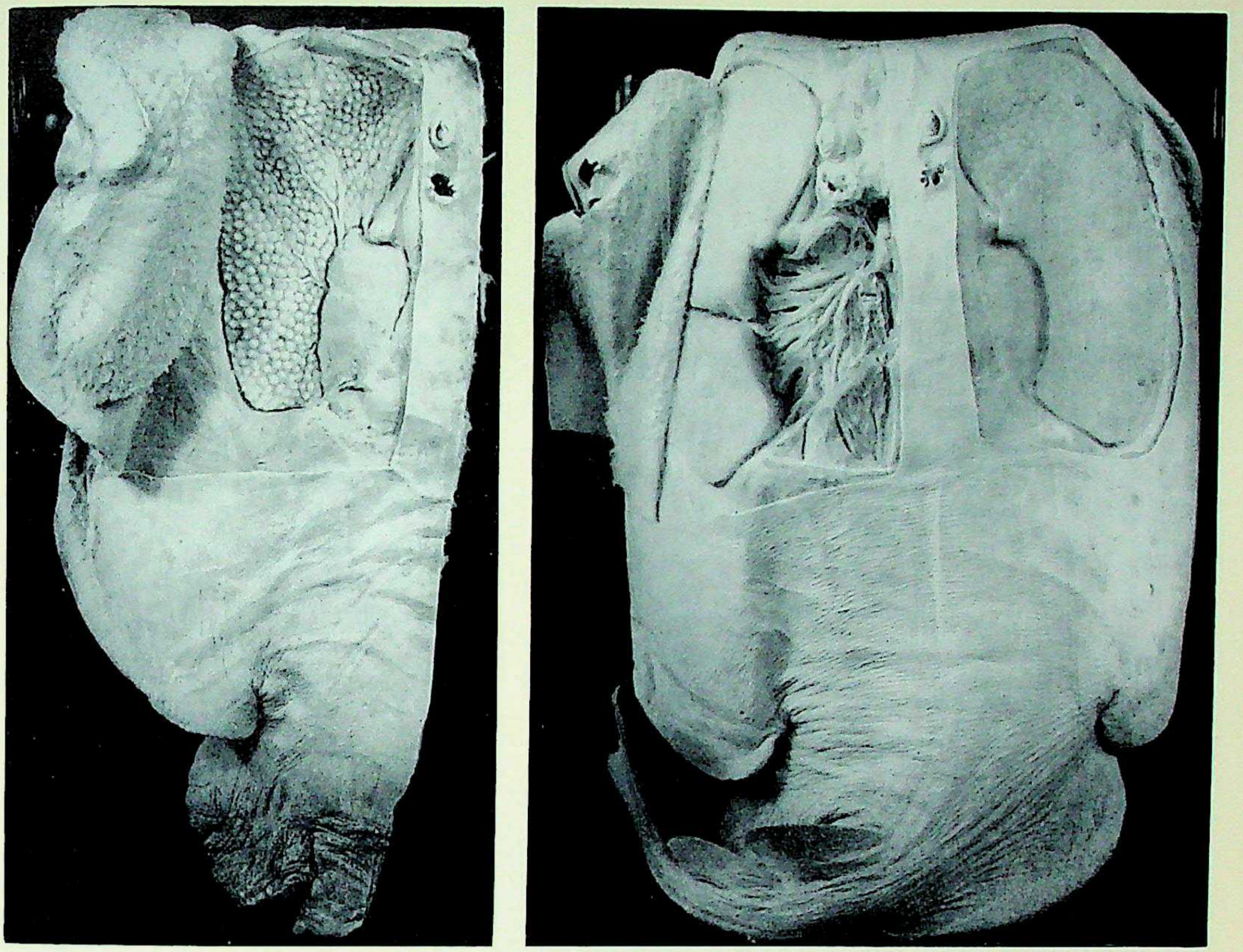
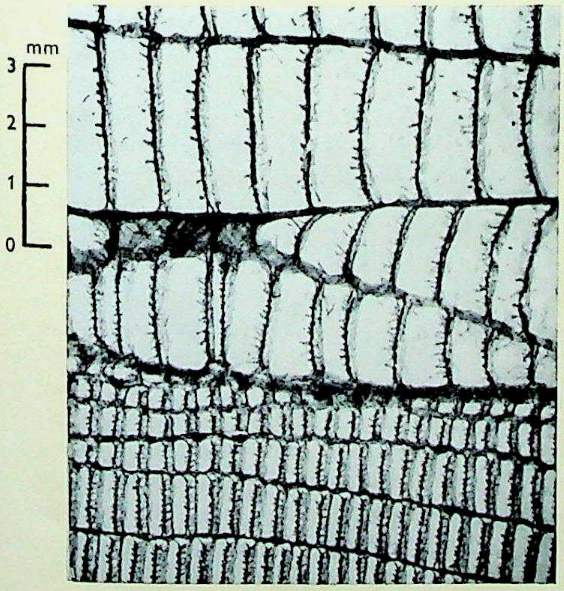
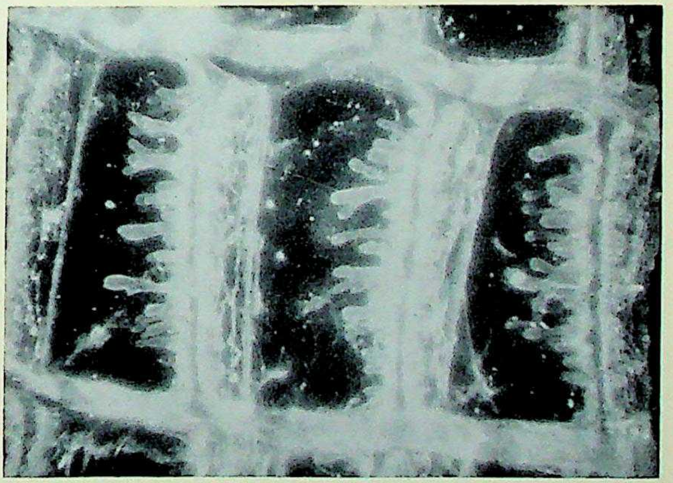


FIGURE 1 – *Two specimens of* Torpedo *dissected by John Hunter to reveal the electric organs and their nerve supply.*

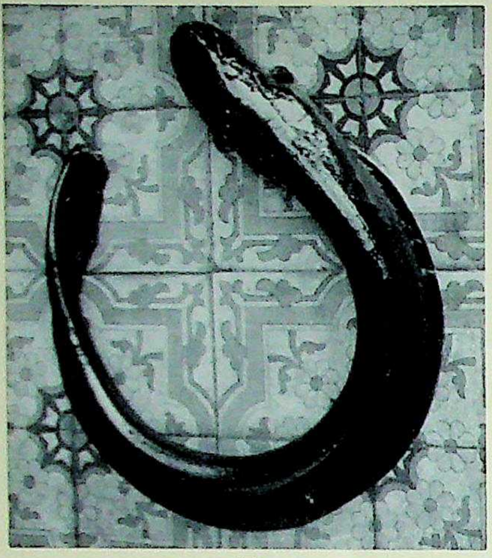


(a)



(b)

FIGURE 2 – *Photomicrographs of sections through the electric organ of* Electrophorus electricus. (a) *is taken at a place where the organ of Sachs (electroplates widely spaced) overlaps the main electric organ (closer spacing). For* (b) *the magnification is about five times greater than for* (a), *to which the scale refers. In this species the electroplates are innervated on the side facing the tail of the fish* [9].



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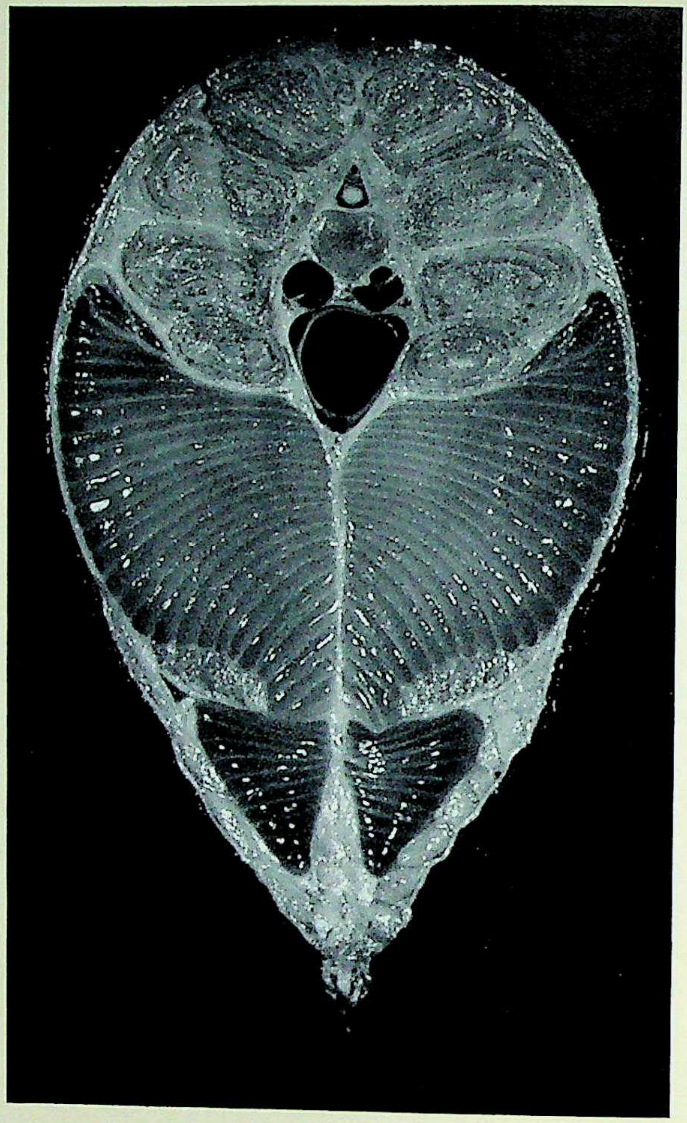

(b)

FIGURE 3 – (a) *A living electric eel and* (b) *a section through the main electric organ. In the uppermost third of the body are the swimming muscles, spinal cord and swim-bladder, while translucent columns of electroplates fill the remainder. Beneath the main organ is a subdivision of the electric organ named after John Hunter.*

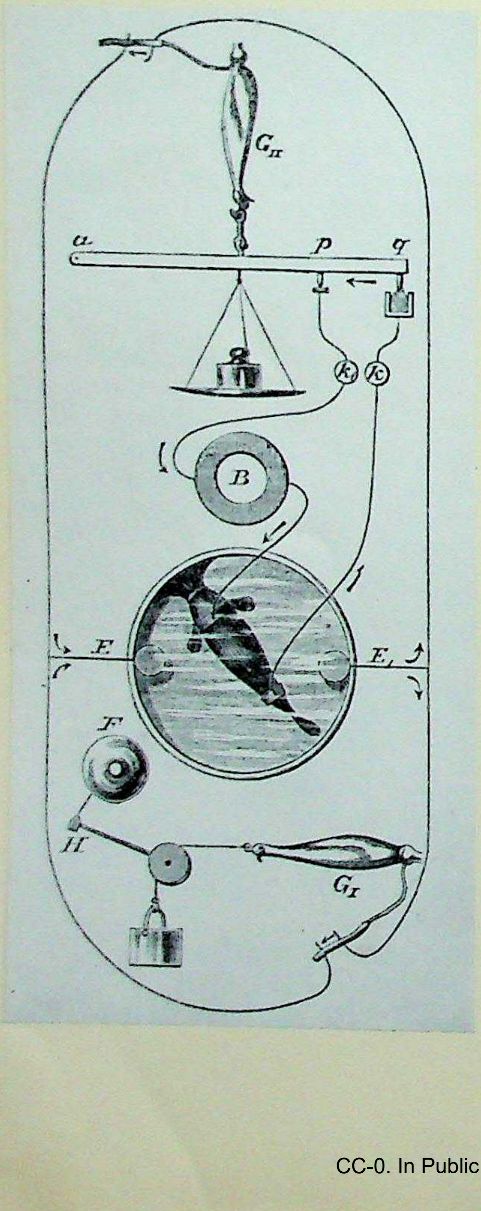

FIGURE 4 (*left*) – *du Bois-Reymond's frog-alarum and frog-interrupter. One frog nerve-muscle preparation* (G_I) *was used to ring a bell when the fish discharged, while another* (G_{II}) *served to disconnect the galvanometer* (*B*) *after the first pulse of the group had been measured.*

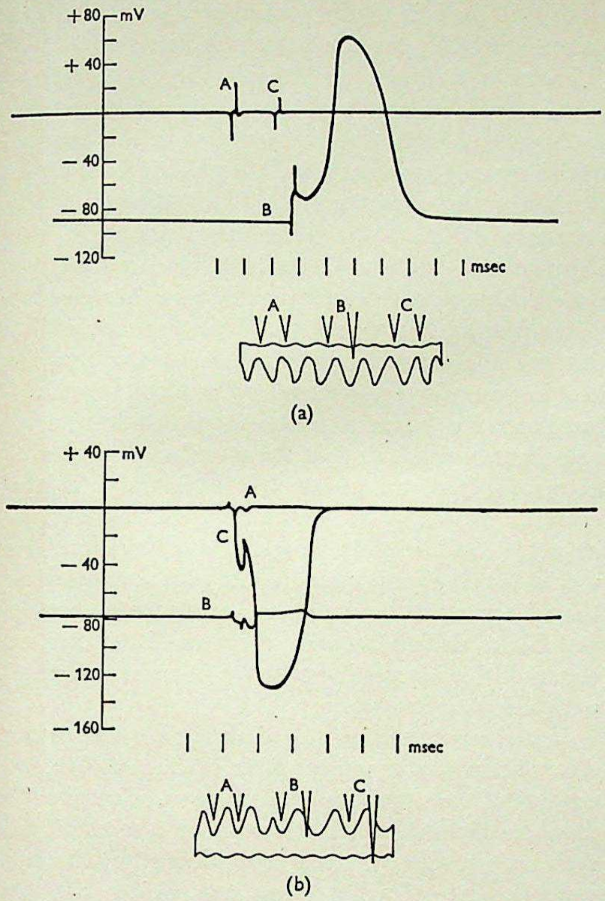

FIGURE 5 – *Microelectrode recordings of the membrane potentials in the electroplates of* Electrophorus electricus, *approaching* (*a*) *through the innervated face,* (*b*) *through the non-nervous face* (*indicated diagrammatically by the presence of papillae*). *The action potential is preceded by a stimulus artifact, which was not perfectly synchronized on successive sweeps* [9].

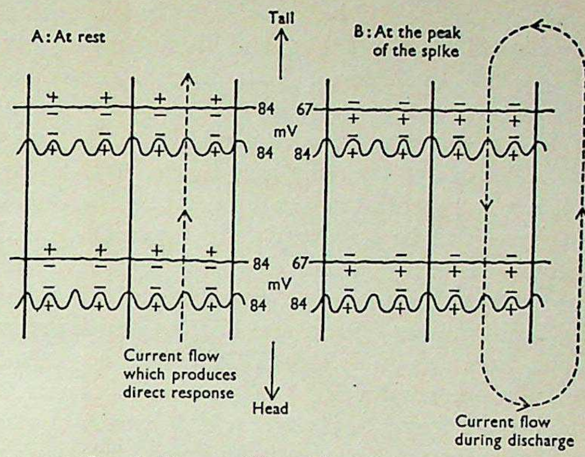
A: At rest
Tail
B: At the peak of the spike
84
67
mV
84
84
84
67
mV
84
84
Current flow which produces direct response
Head
Current flow during discharge

FIGURE 6 – *A diagram illustrating the way in which the electroplates of* Electrophorus *discharge additively. The figures are average results for a number of specimens* [9].

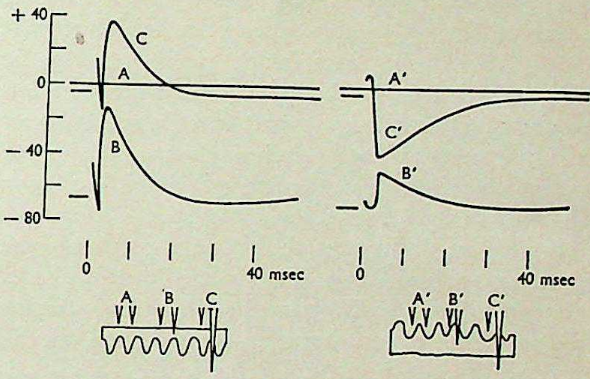

FIGURE 7 – *Microelectrode recordings of the membrane potentials in electroplates of* Raia clavata. *In this species there seems to be, in contrast to the state of affairs in* Electrophorus (*figure* 5), *an appreciable voltage drop across the non-nervous face; note also the difference in time scale and shape of the response* [24].

at the end-plate consists in a reduction of the membrane potential towards zero in the fashion predicted by Bernstein, and does not involve the substantial reversal in polarity which is observed elsewhere in nerve and muscle. Since in *Electrophorus* there is certainly a large reversal in potential (figure 5), and since, as was first shown by D. Albe-Fessard and her collaborators [12], the nervous face of the electroplate can be directly triggered by applied electric shocks, it has been concluded that the electroplate should be regarded as a modified muscle fibre, not as a modified motor end-plate. The distinction has been amplified by Grundfest's recent work [10], which suggests that the mainly muscle-type membrane of the nervous face is interspersed with junctional regions which have much in common, both in electrical behaviour and in function, with motor end-plates. In other species the situation may be different, and in *Torpedo* and *Raia* it is probable that the electroplates can legitimately be thought of as greatly overgrown motor end-plates, containing little or no muscle-type membrane. Microelectrode recordings in *Raia* (figure 7) have shown that here the potential across the nervous face is not reversed to any great extent during activity, and its time course is strikingly like that of an end-plate potential. In these two elasmobranch fishes, moreover, the electric organ is not directly excitable, and can be made to discharge only by stimulating the attached nerves; also, in contrast to *Electrophorus*, treatment with the drug curare can put the electric organ completely out of action. However, it is not surprising that there should be some variation in the mode of discharge of individual electric organs, since they have evidently been evolved quite independently in the various families of electric fishes, and there is no reason why their evolution should have followed an identical course in every case.

The question as to what gives rise to the initial polarization of the cell membrane, and to the change in potential across the nervous face during activity, can be answered only by analogy with nerve and muscle, whose electrical properties have been studied much more intensively with modern techniques than have those of the electric organ. The basis for A. L. Hodgkin's ionic hypothesis of nervous conduction [13] is that all excitable tissues are found to contain a high internal potassium concentration and low internal sodium concentration, as compared with the high sodium and low potassium of the body fluids in which they are bathed. There is evidence that the electric organ of *Electrophorus* is no exception in this respect [14]. The resting membrane potential may be said to arise from the potassium concentration gradient, since the quiescent membrane behaves as if it were almost exclusively permeable to potassium ions. The action potential has been shown to result from a large but strictly transient increase in the permeability of the membrane towards sodium ions. The immediate source of energy to provide the currents which flow during propagation of an impulse—and hence, in all probability, during the discharge of the electric organ—is the entry of a small quantity of sodium into the cell, followed by the leakage of an equal amount of potassium from it. The consequent mixing of the ionic contents of the cell with those of its surroundings must later be reversed, and this appears to be achieved by an active transport mechanism which draws its energy supply from cellular metabolism and is capable of simultaneously extruding sodium and absorbing potassium against the concentration gradients [15]. However, although the working both of the conduction mechanism and of the so-called 'sodium pump' have been examined in some detail in a variety of excitable tissues, establishing beyond doubt that the postulated sequence of permeability changes and the ensuing uphill transfer of ions do occur, it must be added that there is as yet no indication concerning the precise nature, on a molecular scale, of the processes involved in the passage of sodium and potassium ions across the cell membrane. It should be noted that the permeability changes caused by the release of acetylcholine at the motor end-plate are somewhat different from those outlined above [11], but that the mixing of ions is again probably the immediate source of energy for the potential changes.

There is one electric organ—that of *Malapterurus*—to which much of what has just been said apparently does not apply, because in this species the electroplates are thought to be derived from glandular tissue, not muscle. *Malapterurus* is also aberrant in that the innervated faces of the electroplates become electrically positive during the discharge, not negative as in all other electric fishes (see figures 5 and 7). This suggests either that the initial resting potential across the nervous face has a normal polarity (inside of cell negative) but increases during activity instead of decreasing or being reversed, or that the membrane potential decreases during activity but is initially in the opposite direction (inside of cell positive) to that in nerve and muscle fibres. Both explanations would involve ionic movements unlike those that have been studied elsewhere, and it will not be possible to decide between them until the electric organ of this interesting fish has been investigated with microelectrodes.

It is clear that in no case does the electric organ discharge spontaneously; it is always under the control of the central nervous system. Even in the few electric fishes which produce a continuous series of pulses at a fixed repetition rate which is independent of what they are doing at any moment, local cooling of the brain has been shown to reduce the frequency [16]. The anatomy of the motor pathways from the brain to the electric organ has received some attention, and most electric fishes have been found to have particularly large nerve cells in their spinal cords (or, in *Torpedo*, in the brain itself), which give rise to the nerves connected to the electroplate. In *Torpedo* all parts of the electric organ are roughly equidistant from the brain, but the question arises why, in a fish as long—perhaps six feet—as *Electrophorus* may be, there are not serious differences in overall conduction time between nerve impulses triggering the opposite ends of the organ. As was shown by C. W. Coates, R. T. Cox, W. A. Rosenblith, and M. V. Brown [17], the whole organ in fact discharges almost synchronously, as it has to do if the maximum voltage is to be achieved. This problem has recently been examined by D. Albe-Fessard and H. Martins-Ferreira [18], who have found that the discrepancies in conduction time along the spinal cord are compensated in several ways, so that instead of the initiation of the discharge being spread over a calculated 12 msec, it is compressed within a period of about 1·5 msec.

It is interesting to speculate how the discharge of *Malapterurus* is synchronized, since this species is, as in other respects, unique in having all the electroplates in each half of its electric organ innervated by the branches of a single nerve fibre, which would seem to rule out some of the compensation mechanisms described for *Electrophorus*.

Not the least interesting aspect of the physiology of electric fishes is the use they make of their electric organs. One has only to throw a frog into a tank full of electric eels, and to watch it being stunned and swallowed, to convince oneself that *Electrophorus* employs its electricity offensively, but this kind of observation is less easy to make with *Torpedo*. However, D. P. Wilson [19] at Plymouth has persuaded specimens of *Torpedo nobiliana* in an aquarium to attack dead fish towed through the water on a wire, and has described the way in which the prey is enveloped by the pectoral fins of the *Torpedo* before it discharges. There is surprisingly little direct evidence that the other fishes with relatively large electric organs do habitually use their powers for offensive purposes, though it has been suggested that *Malapterurus* employs its discharge to make other fishes disgorge their food. Since all electric fishes seem to discharge most readily when touched or alarmed in any way, it is possible that in many species the main role of the discharge is defensive, and Wilson [19] has seen *Torpedo* apparently discharging in order to drive away intruders. More investigations of the mode of life of electric fishes are needed to settle this point.

As far as the small electric fishes are concerned, an important new field of research has recently been opened up with the discovery by H. W. Lissmann [20] in Cambridge, and by C. W. Coates and his colleagues [16, 21] in New York, that *Gymnarchus niloticus* and various mormyrids and gymnotids produce a continuous series of pulses which seem to serve the purpose of a direction-finding transmitter. In *Gymnarchus* the repetition rate is remarkably constant at about 300 pulses/sec, but in most other species the pulse frequency varies from time to time, perhaps with the degree of interest taken by the fish in its surroundings. This is particularly obvious in the case of *Electrophorus*, which produces (probably from that part of the tail end of its electric organ where the electroplates are most widely spaced, called the organ of Sachs) small direction-finding pulses as well as the lethal groups of large pulses already described [9]. A stationary electric eel is electrically silent, but as soon as it begins to move, it transmits pulses at rates up to about 50/sec [22]. Lissmann [20] has shown that *Gymnarchus* can differentiate between conductors and non-conductors placed in the water beside it, in all probability because it is extremely sensitive to changes in the pattern of electric current flow in the water around it during the discharge. It is not yet known how the sensory side of the direction-finding system works, nor even where the detectors are located, apart from the observation of Coates [22] that lacquering the head of *Electrophorus* interferes with its direction-finding abilities.

Charles Darwin [23] found difficulty in explaining the evolution of the electric organ, because of the apparent absence of any transitional stage between no organ and the extreme development of one in fishes like *Electrophorus*. The existence of small direction-finding transmitters in the gymnotids and mormyrids helps to bridge the gap, but by no means solves the whole problem, since there is no evidence that in the other four kinds of electric fish (*Torpedo*, the rays and skates, *Astroscopus*, and *Malapterurus*) the electric organ is ever used for direction-finding. In any case, the first three of these families live in salt water, where one would expect the range of an electric direction-finding system to be very limited. The evolutionary history of the electric organ remains an unsolved, but most interesting, question.

ACKNOWLEDGMENT

I am indebted to Miss J. Dobson, Mr Edwards, and the Royal College of Surgeons for the photographs in figure 1; to Dr A. Couceiro for those in figure 2; and to the *Journal of Physiology* for permission to reproduce figures 2, 5, 6, and 7.

REFERENCES

[1] ADANSON, M. 'Histoire naturelle du Sénégal'. Bauche, Paris. 1757.
[2] WALSH, J. *Phil. Trans.*, **63**, 461, 1773.
[3] WILLIAMSON, H. *Ibid.*, **65**, 94, 1775.
[4] HUNTER, J. *Ibid.*, **63**, 481, 1773; *Ibid.*, **65**, 395, 1775.
[5] DU BOIS-REYMOND, E. In 'Biological Memoirs. Physiology of nerve, muscle, and the electric organ'. Oxford University Press. 1887.
[6] BERNSTEIN, J. 'Elektrobiologie'. Vieweg, Braunschweig. 1912.
[7] BERNSTEIN, J. and TSCHERMAK, A. *Pflüg. Arch. ges. Physiol.*, **112**, 439, 1906.
[8] LING, G. and GERARD, R. W. *J. cell. comp. Physiol.*, **34**, 383, 1949.
[9] KEYNES, R. D. and MARTINS-FERREIRA, H. *J. Physiol.*, **119**, 315, 1953.

[*Continued overleaf.*

REFERENCES (*continued*)

[10] ALTAMIRANO, M., COATES, C. W., GRUNDFEST, H., and NACHMANSOHN, D. *J. gen. Physiol.*, **37**, 91, 1953. ALTAMIRANO, M., COATES, C. W., and GRUNDFEST, H. *Ibid.*, **38**, 319, 1955.

[11] KATZ, B. and DEL CASTILLO, J. *Progr. Biophys. biophys. Chem.*, **6**, 122, 1956.

[12] ALBE-FESSARD, D., CHAGAS, C., and MARTINS-FERREIRA, H. *C.R. Acad. Sci., Paris*, **232**, 1015, 1951.

[13] HODGKIN, A. L. *Biol. Rev.*, **26**, 339, 1951.

[14] DAVSON, H. and LAGE, H. V. *Ann. Acad. bras. Sci.*, **25**, 303, 1953.

[15] HODGKIN, A. L. and KEYNES, R. D. *J. Physiol.*, **128**, 28, 1955.

[16] COATES, C. W., ALTAMIRANO, M., and GRUNDFEST, H. *Science*, **120**, 845, 1954.

[17] COATES, C. W., COX, R. T., ROSENBLITH, W. A., and BROWN, M. V. *Zoologica, N.Y.*, **25**, 249, 1940.

[18] ALBE-FESSARD, D. and MARTINS-FERREIRA, H. *J. Physiol. Path. gén.*, **45**, 533, 1953.

[19] WILSON, D. P. *J. Mar. biol. Ass. U.K.* **32**, 199, 1953.

[20] LISSMANN, H. W. *Nature, Lond.*, **167**, 201, 1951.

[21] COATES, C. W. *Elect. Engng, N.Y.*, **69**, 47, 1950.

[22] *Idem. Anim. Kingd.*, **57**, 182, 1954.

[23] DARWIN, C. 'The Origin of Species'. Murray, London. 1859.

[24] BROCK, L. G., ECCLES, R. M., and KEYNES, R. D. *J. Physiol.*, **122**, 429, 1953.

Book reviews

ASTRONOMY FOR AMATEURS

Atlas du Ciel, *by Vincent de Callataÿ. Pp.* 157. *Les Éditions de Visscher, Brussels.* 1955. *Belg. fcs* 450 *net.*

This atlas has been designed for amateurs who wish to observe the sky and to identify particular objects without optical aid. It contains 45 plates, in which the stars are shown as white spots on a black ground, to simulate as nearly as possible the actual appearance of the sky. The old mythological constellation figures are not shown, nor are any identifications given on these charts, but the brightest stars are connected by fine lines to assist recognition. Nine of the plates are in the form of planispheres, depicting the sky as seen from different latitudes; the remainder, which are on a larger scale, cover the entire sky in detail. No stars fainter than the 5th magnitude are included.

Accompanying the plates are small-scale charts, on which the names of the constellations and their boundaries, as fixed by the International Astronomical Union, are given, as also the names or designations of the brighter stars. The principal objects of interest in each constellation are listed and described. Appended to each plate is some textual matter relating to some object or objects in the area of the sky concerned. These textual comments have been planned to give collectively a brief elementary descriptive account of modern astronomy. They are not given in a logical sequence, but a key has been provided for the benefit of beginners, indicating the order in which they should be read.

The atlas can be strongly recommended to those who wish to star-gaze without optical aid. The first nine plates form its least satisfactory feature, the magnitudes of the stars on them not being at all adequately distinguished by the sizes of the star disks; they serve, however, to show the relative positions in the sky of the various constellations.

H. SPENCER JONES

COMBUSTION

Fifth Symposium (International) on Combustion, *The Combustion Institute. Pp.* xxvi + 802. *Reinhold Publishing Co., New York; Chapman and Hall Limited, London.* 1955. 120*s. net.*

Since the war, three major combustion symposia have been held in America, at the University of Wisconsin in 1948, at Pittsburgh in 1952, and this last at the Massachusetts Institute of Technology in 1954. At the Pittsburgh meeting the emphasis was deliberately placed on the more physical aspects of combustion, and at Massachusetts on combustion in engines and on combustion kinetics.

There are eleven review articles, six of them on problems connected with various types of engine and five on kinetics, together with ninety original papers. Of the 101 contributions 59 are from the U.S.A. and 24 from Great Britain. Many of the original papers describe work which has been or will be published elsewhere, but as the reputation of the symposia grows there is an increasing tendency for authors to publish only in the symposium proceedings, now controlled by the new Combustion Institute, so that the volumes become essential as the only source of some original work as well as a most valuable and fairly complete guide to current research trends. A minor weakness in presentation is the absence of abstracts with the papers.

A. G. GAYDON

NUCLEAR PHYSICS

Introductory Nuclear Physics (*second edition*), *by David Halliday. Pp.* ix + 493. *John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1955. 60*s. net.*

There are now several elementary books on nuclear physics, but for sheer scope this book is almost certainly unbeaten. No part of the subject that this reviewer can think of is not given at least a mention, and the formidable list of references seems complete to the end of 1954. Here truly is physics. To say that the book is well written, with clear diagrams and an excellent index, would appear to place it beyond criticism.

This is not so, however. A consequence of the attempt to cover so much is that on almost every page one finds the frustrating phrase 'it can be shown'. Furthermore, references as to where it is shown are frequently to original publications, which are several removes in difficulty from this book, even when the matter has in fact long since been treated in review articles or books. A sensible selection of books and articles for further reading would certainly be more useful to the student than the list of references given. And it would almost, though not quite, nullify the above criticism.

A strange inclusion in this second edition is a short chapter on elementary quantum mechanics. A student who does not know a good deal more quantum mechanics than is given there should not even start on this book.

L. R. B. ELTON

FUNDAMENTAL PHYSICS

Niels Bohr, and the Development of Physics, *edited by W. Pauli, with the assistance of L. Rosenfeld and V. Weisskopf. Pp. vii* + 195. *Pergamon Press Limited, London.* 1955. 30*s. net.*

Two of these essays (Darwin, Heisenberg) are historical, while the remainder, by leading figures from seven countries, look to the future and treat problems on the open frontiers of quantum theory. True to its purpose, the *Festschrift* provides a feast of information on the current position at many growing points of fundamental physics, such as the relation of quantum theory and relativity, quantum electrodynamics, superconductivity, and the nucleus.

But there is a sting, for the spirit of Bohr haunts the feast, ironically reminding us of what is lacking today. Many of the essayists say, in effect, that the Age of Bohr is nearly over, that the power of the Correspondence Principle is waning, and that theoretical research is being forced to rely more and more on mathematical virtuosity. The report on the latest work in the quantum theory of fields (Landau, from Moscow) warns us that far-reaching changes may be necessary in the theory of mesons. Yet it is becoming increasingly doubtful whether the help needed for this and other pressing tasks can be obtained from mathematical considerations alone. An improved version of atomism, purged of some unnecessary feature still lurking in present methods, and a more profound epistemology of measurement may be required for the step which will reduce current complexities and open up the next Age.

L. L. WHYTE

CHEMICAL EQUILIBRIUM

The Principles of Chemical Equilibrium, *by K. G. Denbigh. Pp. xxi* + 491. *Cambridge University Press, London.* 1955. 42*s. net.*

Professor Denbigh has communicated much of his enthusiasm for thermodynamics in a thoughtful and stimulating text-book intended for students of chemistry or chemical engineering in the last year of their degree courses. Theoretical principles are discussed fairly fully, and their applications are illustrated by over a hundred problems, many of them chosen from the examinations for the Cambridge University chemical engineering degree, together with answers and comments.

Part I (The Principles of Thermodynamics) establishes from the First and Second Laws the significance of the various thermodynamic functions and their derivatives, which are used in Part II (Reaction and Phase Equilibria) to discuss reactions involving gases, the phase rule, ideal and non-ideal solutions, and ionic equilibria. In Part III (Thermodynamics in relation to the Existence of Molecules) statistical mechanics is developed in terms of the Gibbs ensemble to include monatomic gases, perfect crystals, and the Third Law, and brief introductions to chemical kinetics, transition-state theory, regular solutions, and adsorption. Particularly useful treatments are those of the conditions of equilibrium for several independent reactions, the derivation of the phase rule, and the relation between the kinetic expressions for the forward and reverse components of a reaction. Some readers, however, may be disappointed not to find more information about the statistical calculation of equilibrium constants and more guidance on where to seek reliable numerical data.

K. W. SYKES

THEORY OF RESONANCE

Resonance in Organic Chemistry, *by G. W. Wheland. Pp. xiii* + 846. *Chapman and Hall Limited, London.* 1955. £6 *net.*

Professor Wheland's earlier book, *The Theory of Resonance*, was published in 1944 and gave the first comprehensive account of these new ideas in their application to organic chemistry. The present book, which entirely supersedes the older one, is a notable addition to the literature, since, with relatively minor omissions, it covers the whole field of resonance in organic chemistry, including structure and reactivity; furthermore the usage of the word resonance is enlarged to cover the alternative theory of molecular orbitals. This is an entirely desirable addition, since we now know enough of both the limitations and successes of the valence-bond and molecular-orbital types of approximation to distrust either unless both agree. Wheland himself has been in this field since its beginning and writes with authority. He is particularly clear in his evaluation of resonance as a phenomenon or as a way of thinking and talking about molecules. There is none of the slipshod argument which has so often dogged discussion of the applications of resonance in the past. There is a full collection (90 pages) of experimental bond lengths and bond angles, which will enhance the value of the book to some of its readers. This volume deserves the same success as its predecessor.

C. A. COULSON

ROGER ADAMS

The Roger Adams Symposium, *prepared by C. S. Marvel. Pp. ix* + 140. *John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1955. 30*s. net.*

The influence of Roger Adams on the development of chemical teaching and of research and its application has been unsurpassed in the United States and has extended directly and indirectly in every direction. He has manufactured chemical doctors on the grand scale, and helped them to publish their work and fit themselves for industrial activities. Furthermore, he has penetrated every nook and cranny of the public service, wherever chemistry is relevant. The six papers presented at a symposium in his honour are contributed by former Ph.D. students (1918–29) and are all of individual interest, while together presenting a cross-section of Adams' interests. Needless to say there are many gaps, but that was inevitable in the circumstances.

The president of the Abbott Laboratories, Ernest H. Volwiler, depicts clearly the endearing qualities and outstanding achievements of one whom he justly describes as the acknowledged leader of American chemistry. The other five papers are concerned with advances in knowledge made by the respective authors. The longest section, by Wallace R. Brode of the National

Bureau of Standards, is a most useful monograph on the steric effects in dyes, a subject that might easily be overlooked in a discussion of the relation of molecular structure and light absorption. The idea of group interference in space is very significant here, and Adams' studies in this region were fundamental. Professor Johnson of Cornell University gives a clear account of his remarkable work on the unusual gliotoxin molecule, and Professor McElvain, University of Wisconsin, discusses the chemistry of nepetalic acid, a curious derivative of *cyclo*pentane. Professor Shriner of the State University of Iowa deals with some new reactions of pyrylium salts. The final paper, by Wendell M. Stanley of the Virus Laboratory, University of California, is a stimulating exposition of chemical studies on viruses. Professor C. S. Marvel, for many years a colleague of Adams, has suggested, in the wide range of topics, a corresponding breadth of outlook of the man honoured.

The present volume can be warmly recommended to the many friends of Roger Adams throughout the world. But the appeal is wider because of the absolute value of all the contributions to this outstanding two-day symposium.

R. ROBINSON

BIOCHEMICAL SYNTHESIS

Biochemical Preparations, Volume 4, *edited by W. W. Westerfield. Pp. vii +* 108. *John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1955. 30*s. net.*

With the appearance of this volume, 'Biochemical Preparations' is on the way to becoming as well recognised as 'Organic Syntheses'. The series offers to the biochemist carefully checked methods of preparing substances not always easily accessible to him. For some to whom small supplies of even the commonest biochemical substances are unavailable they provide means of preparation relatively cheap in starting materials. The present volume describes the preparation by synthesis, by use of enzymes, or by isolation, of 21 substances, among which are included α-*d*-galactose-1-phosphate, α-*d*-glucose-1-phosphate, homogentisic acid, lecithin, α-lactalbumin, alcohol dehydrogenase, urocanic acid, and glutamic acid. The commendable features of each method are the footnotes, which should help in the avoidance of difficulties, and the description of the properties and evidence of purity of substances. Alternative procedures are given for the preparation of *d*-glutamic acid; in one, Crookes strain of *Escherichia coli* serves as a source of decarboxylase for the destruction of the *l*-antipode, and in the other *Clostridium perfringens*. There is something to be said for the duplication of biochemical preparations in that it allows a worker to choose one that he can carry out with the facilities he has at hand and to try out another if he fails with one. Although the series will largely be used by research workers, it should provide many useful examples of preparations for the practical instruction of students.

J. R. P. O'BRIEN

PHYSIOLOGICAL CHEMISTRY

Cole's Practical Physiological Chemistry (*tenth edition*), *revised and rewritten by E. Baldwin and D. J. Bell. Pp. x +* 263. *W. Heffer and Sons Limited, Cambridge.* 1955. 21*s. net.*

Not a few biochemists and physiologists in the early years of this century have had their first introduction in physiological chemistry through the medium of Cole's book. The present edition, following the ninth after some twenty years, is appropriately dedicated to his memory. It retains the essence of earlier editions: principles are well explained, well illustrated, and further exemplified by experiments of a simple direct nature. There has been some rearrangement of chapters and extensive rewriting. Still, many of the original experiments are retained and some remodelled; all are concerned with readily accessible materials. The authors frankly state that the analytical methods discussed are not the most up to date nor the most accurate, but are those which have been well tried and which can prove successful in the hands of students using simple apparatus. It is a book that will give a student, particularly one who has medicine in mind as a career, a sound practical introduction to elementary physiological chemistry in its qualitative and quantitative aspects. It may be that this is the right objective for students for whom a familiarity with the fundamental characteristics of biological substances is all that is required in their careers. The essence of Cole is still there; the clear and direct introductory explanations to the practical experiments and the valuable instructive footnotes, now not so profuse, to experiments.

J. R. P. O'BRIEN

GEOLOGY

L'Évolution de la Lithosphère. I. Pétrogenèse, *by H. Termier and G. Termier. Pp.* 653. *Masson et Cie., Paris.* 1956. *Paper covers, fcs* 8000 *net; cloth, fcs* 8800 *net.*

One cannot but admire the industry of the two authors when one reflects that this monumental work forms only one part of a projected series of four volumes which together will make their *Traité de Géologie.* The present volume is the second of the series and deals with the origin of igneous and metamorphic rocks. It is distinguished by the insistence of the authors that petrological problems are most fruitfully approached with their geological setting in mind. To this end a valuable synthesis of recent studies of the field-relations of rocks has been compiled to illustrate the authors' arguments. While the Termiers have not neglected their own and their colleagues' work in North Africa, they have brought together illustrations from literally every quarter of the globe. It is to be regretted that we are not given a more critical review of some of this work. For example, the transformist interpretation of the Bushveldt complex is cited at length, and the unwary reader might suppose that no other view was tenable.

The earlier chapters deal in a clear and original manner with such topics as crystal structure and crystal growth, geochemistry, the sources of energy within the earth, and the age of the earth. In the main part of the work an acquaintance with the basic facts of petrology is assumed, but to a reader with that acquaintance this book can be recommended as a fascinating study of the geology of the hard rocks. The text is clear and the maps and diagrams are excellent—perhaps more could have been included with advantage.

H. H. READ

STRATIGRAPHIC GEOLOGY

Stratigraphic Geology (*fourth edition*), *by M. Gignoux, translated by G. G. Woodford. Pp. xvi +* 698. *Bailey Brothers and Swinfen Limited, London; W. H. Freeman and Company, California.* 1955. *$9.50 net.*

In reviewing a work as gigantic as this it would be easy to write only criticisms. One knows that the late Professor Gignoux made mistakes in his first edition and did not correct all of them in the three subsequent printings. Sometimes he failed to include the results of new work which drastically modified earlier conclusions, and occasionally he incorporated such changes in a part of his book without allowing for their effect elsewhere. Whatever criticisms a reviewer might make of the original book would apply equally to this translation. Moreover, any translator of a geological work published even five years previously is faced with the problem of whether to rewrite certain parts or to perpetuate ideas which have in the meantime become obsolete. Thus, by retaining unchanged Gignoux's classification of the Pliocene and Pleistocene, the book becomes at variance with the unanimous recommendations of a committee of the International Geological Congress.

The translation follows too closely the French idiom and consequently rarely lets one forget the original source, while the illustrations have not been redrawn but have been photographed from the French editions, with the result that the diagrams lose in clarity.

Nevertheless, Gignoux's *Géologie Stratigraphique* is not merely the only book of its type, it approaches to being a masterpiece. It is invaluable to the student, professional or amateur, and this translation has made it available to a host of readers who otherwise might have been unable to appreciate it adequately. For doing this the publishers and the translator deserve our gratitude.

F. W. SHOTTON

GENETICS AND METABOLISM

Genetics and Metabolism, *by R. P. Wagner and H. K. Mitchell. Pp. xi + 444. John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1955. 60*s. net.*

The rapid approach of genetics and biochemistry to one another has led recently to the appearance of a number of books dealing with the combination of the two. The present book may most simply be described as complementary to Haldane's 'Biochemistry of Genetics', each filling the gaps in the other. The introductory chapters are the least satisfactory. They begin with the gene, but the gene is not the beginning of genetics: it comes at the half-way point. It demands, for example, a better understanding of meiosis than the authors offer. The telegraphic American abstracting style which they use is sometimes ill-constructed and obscure. Ideas of theory and scientific method have also troubled the authors too little: if they would drop their 'proofs' and consider the evidence they would both learn and teach their subject better. As it proceeds, however, the book improves in scope and understanding. It brings together for the first time a large and connected body of knowledge, both solid and speculative. Its influence among research workers should be far-reaching and good.

C. D. DARLINGTON

EMBRYOLOGY

Principles of Embryology, *by C. H. Waddington. Pp. x + 510. George Allen and Unwin Limited, London.* 1956. 45*s. net.*

It is a curious fact that a hundred years ago the distinction between the science of embryology and of genetics was blurred, for Darwin, following the Hippocratic writer, conceived of the resemblance between parent and offspring in terms of little particles contributed from all parts of the body of the parent which were supposed to control the production of the corresponding parts of the offspring. By this means it was hoped to explain not only hereditary resemblance but embryonic development.

Then came the great analyses of genetics by Mendel and of embryology by Roux, as a result of which genetics specialized in the distribution to the offspring of hereditary characteristics, while embryology concerned itself with the conversion of the egg into the adult. The former dealt with the events during the two cell-generations which comprise the maturation of the germ-cells and their fertilization, while the latter grappled with what happened during the fifty cell-generations which separate the fertilized egg from the full-grown man.

Now these two sciences are coming together again, for the factors concerned in hereditary resemblance are clearly also responsible for controlling development. After outlining the salient facts of embryology, Professor Waddington deals with the role of Mendelian genes in controlling development pathways, the activation of genes by the cytoplasm and their inhibition, and the synthesis of new substances. He is then able to formulate principles governing the differentiating system, the origin of pattern, and the production of shape. He has produced a most stimulating book which will be essential both to geneticists and embryologists.

G. DE BEER

ANTIMETABOLITES AND CANCER

Antimetabolites and Cancer, *edited by C. P. Rhoads. Pp. vi + 312. American Association for the Advancement of Science, Washington.* 1955. $5.75 *net.*

This collection of papers, although given at a Symposium in December 1953, constitutes a review of the field which is still, in most of the essentials, up to date. Admirable papers by Hitchings, Burchenal, Mandel, Lansford and Shive, Parks, and G. B. Brown deal with widely investigated aspects of the use of purine, pyrimidine, and folic acid analogues as antimetabolites and describe what is known of their relation to the treatment of experimental and clinical malignant disease.

In this connection, papers by Skipper, and by Nichol and Welch, on the development of resistance by A-methopterin and 8-azaguanine are particularly interesting. Woolley describes the inhibition of mouse-tumour growth by analogues of 1 : 2-diamino-4 : 5-dimethylbenzene (a vitamin B_{12} precursor), and among several interesting papers on the less well explored parts of the field may be mentioned investigations on plant growth and plant tumours by Nickell, of the effect of aminopterin on bone-marrow by Totter; on the use of nucleotide and nucleoside analogues as antimetabolites by Visser; and by Nelson on the effect of antimetabolites in the induction of foetal abnormalities. An interesting paper by Weinhouse on the carbohydrate metabolism of tumour cells brings this important but relatively neglected topic up to date.

This book can be highly recommended to those requiring a stimulating and authoritative account of much of the work done on those antimetabolites which have been investigated thoroughly.

G. M. TIMMIS

LUNG CANCER

Causal Factors in Cancer of the Lung, *by Carl V. Weller. Pp. viii + 113. Charles C. Thomas, Publisher, Springfield; Blackwell Scientific Publications Limited, Oxford.* 1956. 21*s.* 6*d. net.*

Dr Weller's book is on the theme of the day in cancer research—that cigarette smoking is the principal cause of the huge rise in the lung cancer rate in the last few decades. He presents, in not too technical a fashion, the evidence unravelled by the work of the Kennaways, Doll and Hill, Clemmesen, Dorn, Cutler and Loveland, Hammond and Horn, and others.

Dr Weller first uses the statistical material for his treatment of the subject and then discusses the appalling death rate from lung cancer among the miners at the Schneeberg and Joachimstal mines; there are some interesting illustrations of the miners from woodcuts dating back to 1556. He next reviews agents and conditions which have been implicated as carcinogens for the lung: arsenic, radioactivity, silicosis, asbestosis, pneumonitis, chromates, benzpyrene, atmospheric pollutants, urbanization, and tobacco.

However, when Dr Weller has assembled the impressive evidence, if not indeed proof, that cigarette smoking is responsible for something like 80 per cent of the present formidable toll of lung cancer deaths, he becomes extremely cautious on the question of prevention.

The best he can do is to shift the responsibility on to the shoulders of two cancer investigators made of somewhat bolder stuff, for he quotes Maisin and Clemmesen, who stated in 1952: 'May we show the same practical sense as our forefathers, and not look for direct proofs which are out of reach before we transmit experience into practical measures.'

I. HIEGER

BRITISH PHARMACOPOEIA

British Pharmacopoeia 1953: Addendum 1955. *Pp. xvii* + 94. *The Pharmaceutical Press, London.* 1955. 21*s. net.*

The publication of an addendum two years after the last edition of the *British Pharmacopoeia* shows a great determination to keep up with the continuous succession of new medicaments. Perhaps the most generally interesting inclusion is that of Soluble Aspirin Tablets. There are several new monographs, which include important substances like cortisone and oxytetracycline.

The Pharmacopoeia Commission has gradually cast aside one after another the prejudices which formerly governed decisions on what a monograph might contain, with the result that now the *British Pharmacopoeia* has become a useful book for everyone except for the physician! We have, for example, in this addendum monographs on diethylcarbamazine citrate, iopanoic acid, phenindione, and others of which it is safe to say that not one physician in a thousand would know the use. Why cannot a clue be given? Some uses are already given, as for example, the dose of cortisone acetate. Cannot the Commission now take the plunge?

J. H. BURN

AMERICAN MEN OF SCIENCE

American Men of Science (*ninth edition*), *Vol. II* (The Biological Sciences). *Pp.* 1276. *The Science Press, Lancaster, Pa; Bowker Company, New York.* 1955. $20 *net.*

This is the second volume of the new edition of 'American Men of Science', and is devoted to those working in the fields of zoology, botany, medical research, and kindred fields. It includes some thirty thousand names, compared with nearly forty-four thousand in the recently published volume, which deals with physical sciences. Wherever practicable, workers in borderline fields such as biochemistry and biophysics have been offered the choice of appearing in either Volume I or Volume II, but to avoid confusion there are ample cross-references from one volume to the other.

This volume follows much the same style as that for the physical sciences: the only obvious difference between the two volumes—and one which seems as unnecessary as it is inconvenient—is that the page sizes differ so that they range untidily in the bookshelf. It is a mine of concise and comprehensive information, and will be indispensable as a work of reference to all interested in the organization of scientific work in the United States. The nature of the work requires that a general review shall be brief, but brevity is here in no way indicative of lack of appreciation. The preparation of such a work is obviously a heavy undertaking, and one must be grateful to those whose combined efforts brought it to so satisfactory a conclusion.

A third volume on similar lines will cover the social sciences.

TREVOR I. WILLIAMS

SCIENTIFIC BIOGRAPHIES

Biographical Memoirs of Fellows of the Royal Society. *Vol.* I. *Pp.* 263. *The Royal Society, London.* 1955. 30*s. net.*

This is the first of a new series of annual publications continuing the Obituary Notices of Fellows of the Royal Society. The change of title does not reflect any major departure from the style of the former series, but it is none the less felicitous, for the phrase 'obituary notice' suggests a bleakness which these volumes do not deserve. They tell stories of outstanding contributions to science: this is inevitable from the nature of the volume. But they do much more than this: many of them tell moving stories of men who were in no sense narrow specialists but lived full and active lives with a wealth of interests. Were it worth while to refute the criticism, still sometimes heard, that scientists are unemotional materialists, abundant evidence could be found here. This series of volumes can be an inspiration to the present generation; to those of the future they will prove also a unique source of authentic biographical information.

TREVOR I. WILLIAMS

LUDWIG BOLTZMANN

Ludwig Boltzmann, *by Engelbert Broda. Pp. viii* + 152. *Franz Deuticke, Vienna.* 1955. *Paper covers, DM* 9.50 *net; linen, DM* 11 *net.*

Ludwig Boltzmann was the last of the great theoretical physicists of what is now called the classical epoch. In 1906, at the age of sixty-two, he died by his own hand. Planck's first exposition of the quantum theory had, it is true, appeared in 1900 and Einstein's first paper on relativity in 1905, but Boltzmann's best work was over by the turn of the century. He had before then made his fundamental advances in the kinetic theory of gases, at a time when the atomic theory was far from being generally accepted. In particular, he had systematically developed the conception of probability as an essential part of gas theory and he had done his pioneering work as a founder of statistical physics.

Boltzmann was a most interesting character. He was a lecturer who, by his character and clarity, attracted enthusiastic audiences; he was a deep thinker in philosophical matters; he had a keen and dry sense of humour. All these aspects of the man are developed in a most interesting and understanding way in the little book before us, the first, we believe, to be devoted to him. It is divided into three sections—The Man: The Physicist: The Philosopher. The first is particularly valuable because the author has had personal communications from many, including Lise Meitner and Boltzmann's daughter and stepdaughter, who when they were young associated with the great man. Their recollections contribute to a particularly personal and animated picture of one of the pioneers of science.

E. N. DA C. ANDRADE

Some books received

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(*Note.* Mention of a book on this page does not preclude subsequent review.)

ASTRONOMY

Introduction to Astronomy, *by Cecilia Payne-Gaposchkin. Pp.* x + 508. *Eyre and Spottiswoode, London.* 1956. 50*s. net.*

The Planet Venus, *by Patrick Moore. Pp.* 132. *Faber and Faber Limited, London.* 1956. 15*s. net.*

BIOCHEMISTRY

Essays in Biochemistry, *edited by Samuel Graff. Pp.* x + 345. *John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1956. 52*s. net.*

BIOGRAPHY

Robert Hooke, *by Margaret 'Espinasse. Pp. vii* + 192. *William Heinemann Limited, London.* 1956. 21*s. net.*

BIOLOGY

Einführung in die Mikropaläontologie, *by Horst Werner Matthes. Pp. viii* + 348. *S. Hirzel Verlag, Leipzig.* 1956. *DM.* 33.40.

Hormones Hypophysaires Somatotrope et Corticotrope. Croissance et Métabolisme, *by H. Tuchmann-Duplessis. Pp.* 319. *Masson et Cie., Paris.* 1956. *Fcs* 2200.

Proceedings of the Underwater Physiology Symposium, *edited by Loyal G. Goff. Pp. xi* + 153. *National Academy of Sciences—National Research Council, Washington.* 1955. *Paper bound,* $1.50.

La Régulation des Processus Métaboliques dans l'Organisme, *by Théophile Cahn. Pp. xii* + 681. *Presses Universitaires de France, Paris.* 1956. *Fcs* 3000.

BOTANY

A Book of Wild Flowers. 160 *Plates after Watercolours by Elsa Felsko. Notes by Sheila Littleboy. Pp. xi* + 231. *Bruno Cassirer, Oxford; Faber and Faber Limited, London.* 1956. 35*s. net.*

CHEMISTRY

The Determination of Toxic Substances in Air, *edited by N. Strafford, C. R. N. Strouts, and W. V. Stubbings. Pp. xxvii* + 226. *W. Heffer and Sons Limited, Cambridge.* 1956. 35*s. net.*

Geochemistry of Iodine. Bibliography 1825–1954. *Pp. viii* + 150. *Chilean Iodine Educational Bureau, London.* 1956.

Introductory Quantitative Chemistry, *by A. R. Olson, C. W. Koch, and G. C. Pimentel. Pp.* x + 470. *W. H. Freeman and Company, San Francisco; Bailey Bros. and Swinfen Limited, London.* 1956. 42*s.* 6*d. net.*

Modern Chemical Processes, *Vol.* IV, *by the Editors of* Industrial and Engineering Chemistry. *Pp. v* + 202. *Reinhold Publishing Corporation, New York; Chapman and Hall Limited, London.* 1956. 40*s. net.*

The Petroleum Acids and Bases, *by H. L. Lochte and E. R. Littmann. Pp.* 368. *Constable and Company Limited, London.* 1956. 50*s. net.*

Physikalisch-chemisches Rechnen in Wissenschaft und Technik, *by Hans Fromherz. Pp. ix* + 316. *Verlag Chemie G.m.b.H., Weinheim/Bergstr.* 1956. *DM.* 32.50.

CRYSTALLOGRAPHY

Echt oder synthetisch? *by K. F. Chudoba and E. J. Gubelin. Pp.* 156. *Rühle-Diebener-Verlag K.G., Stuttgart.* 1956. *DM.* 18.50.

ENGINEERING

Automatic Process Control for Chemical Engineers, *by N. H. Ceaglske. Pp. xiv* + 228. *John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1956. 54*s. net.*

Dizionario d'Ingegneria, *Vol. V,* RUM–Z, *edited by Eligio Perucca. Pp. xii* + 1046. *Unione Tipografico—Editrice Torinese, Turin.* 1956. *Lire* 12 000.

Fluidization, *edited by D. F. Othmer. Pp. ix* + 231. *Reinhold Publishing Corporation, New York; Chapman and Hall Limited, London.* 1956. 56*s. net.*

Frequency Response, *edited by R. Oldenburger. Pp. xii* + 372. *The Macmillan Company, New York.* 1956. 52*s.* 6*d. net.*

Ingegneria Nucleare, *by F. Mazzoleni. Pp. xii* + 470. *Ulrico Hoepli, Milan.* 1956. *Lire* 4000.

MATHEMATICS

Automatic Digital Computers, *by M. V. Wilkes. Pp.* x + 305. *Methuen and Company Limited, London.* 1956. 42*s. net.*

The Theory of Games and Linear Programming, *by S. Vajda. Pp.* 106. *Methuen and Company Limited, London; John Wiley and Sons Inc., New York.* 1956. 8*s.* 6*d. net.*

MEDICINE

Ciba Foundation Colloquia on Endocrinology, Volume IX. Internal Secretions of the Pancreas, *edited by G. E. W. Wolstenholme and C. M. O'Connor. Pp. xii* + 292. *J. and A. Churchill Limited, London.* 1956. 40*s. net.*

Histamine (Ciba Foundation Symposium in honour of Sir Henry Dale), *edited by G. E. W. Wolstenholme and C. M. O'Connor. Pp. xvi* + 472. *J. and A. Churchill Limited, London.* 1956. 50*s. net.*

Les Mécanismes Cérébraux de la Prise de Conscience, *by P. Chauchard. Pp.* 240. *Masson et Cie., Paris.* 1956. *Fcs* 1300.

Psychopharmacology, *edited by N. S. Kline. Pp.* x + 165. *Publication No.* 42 *of the American Association for the Advancement of Science, Washington; Bailey Bros. and Swinfen Limited, London.* 1956. 32*s. net.*

PHYSICS

The Mathematics of Diffusion, *by J. Crank. Pp. vi* + 347. *Clarendon Press, Oxford.* 1956. 50*s. net.*

Measurement of Small Holes, *by I. A. Grigor'ev.* (*Translated from the Russian by the Department of Scientific and Industrial Research.*) *Pp.* x + 137. *Her Majesty's Stationery Office, London.* 1956. 8*s.* 6*d. net.*

Temperature. Its Measurement and Control in Science and Industry, *Vol.* II, *edited by H. C. Wolfe. Pp.* x + 467. *Reinhold Publishing Corporation, New York; Chapman and Hall Limited, London.* 1955. 96*s. net.*

TECHNOLOGY

Atom Harvest, *by L. Bertin. Pp.* 253. *Secker and Warburg, London.* 1955. 20*s. net.*

Glass, *by G. O. Jones. Pp. vi* + 119. *Methuen and Company Limited, London; John Wiley and Sons Inc., New York.* 1956. 8*s.* 6*d. net.*

High Temperature Technology, *edited by I. E. Campbell. Pp. xiv* + 526. *John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1956. 120*s. net.*

Plastics in the Service of Man, *by E. G. Couzens and V. E. Yarsley. Pp.* 315. *Penguin Books, Harmondsworth, Middlesex.* 1956. 3*s.* 6*d. net.*

Notes on contributors

H. E. HUXLEY,

M.B.E., M.A., Ph.D.,

Was born in 1924 and was educated at Park High School, Birkenhead, and at Christ's College, Cambridge. During the war served as a radar officer in the Royal Air Force, working also at the Telecommunications Research Establishment, Malvern. Research student in the Medical Research Council Unit, Cavendish Laboratory, Cambridge (1948–52), where he was awarded a Ph.D. for a thesis on X-ray diffraction studies of muscle. Subsequently spent two years in the United States as a Commonwealth Fund Fellow, where he continued working on muscle and developed a strong interest in electron microscopy. On his return to the Medical Research Council Unit in Cambridge he became a Fellow of Christ's College. Now an External Staff Member of the Medical Research Council, and Research Associate in the Department of Biophysics, University College, London, where his main interests lie in the study of the molecular structure of biological systems by means of electron microscopy and other techniques.

SIR EDWARD BULLARD,

M.A., Sc.D., F.R.S.,

Was born in 1907 and educated at Repton School and Clare College, Cambridge. He began research under Lord Rutherford in 1929, working on the scattering of slow electrons in gases. In 1931 he took up geophysics and has done experimental work on gravity, seismology, and the measurement of heat flow on land and at sea. From 1950 to 1955 he was Director of the National Physical Laboratory, and is now Assistant Director of Research in Geophysics in the University of Cambridge. He has written extensively on the origin of the earth's magnetic field and on magneto-hydrodynamics.

G. TEMPLE,

C.B.E., M.A., Ph.D., D.Sc., F.R.S.,

Was born in 1901 and was educated at Ealing County School; Birkbeck College, University of London; and Trinity College, Cambridge. From 1932 to 1953 he was Professor of Mathematics at Kings College, University of London, but during the war years was seconded to the Royal Aircraft Establishment, Farnborough. Is now Sedleian Professor of Natural Philosophy, University of Oxford, and Fellow of The Queen's College, Oxford. He is the author of several works on quantum theory and other branches of mathematical physics.

C. DODD,

B.Sc., Ph.D.,

Was born in 1914 and was educated at Durham Grammar School and the University of London. During the war he served in the Ministry of Supply, working in the Royal Society Mond Laboratory, Cambridge, and is now a lecturer at University College, London. His research work has been concerned with the physical properties of liquids in the normal, supercooled and superheated states. In 1955 a grant from the Astor Foundation enabled him to work on bubble chambers at the University of Michigan and to study the various developments of these new detectors in other parts of the United States.

T. M. HARRIS,

M.A., B.Sc., Sc.D., F.R.S.,

Born at Leicester, 1903. Was trained in fossil botany by H. S. Holden at Nottingham and by A. C. Seward at Cambridge. Appointed Professor of Botany at Reading University in 1934. Member of Danish geological expedition to East Greenland 1926–7. Has written numerous papers on fossil plants from Greenland and later from the Yorkshire coast.

R. D. KEYNES,

M.A., Ph.D.,

Born in London, 1919; educated at Oundle School and Trinity College, Cambridge. Fellow of Trinity, 1948–52. Fellow of Peterhouse since 1952, and University Lecturer in Physiology since 1953. From 1940 to 1945 worked for the Admiralty on Asdics and naval radar. Since 1946 his main field of research has been the use of radioactive isotopes to investigate the ionic interchanges of nerve and muscle fibres. In 1951 he spent three months at the Instituto de Biofísica, University of Brazil, Rio de Janeiro, as Visiting Reader in Biophysics.

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